THE EFFECT OF FEEDING A BARLEY/CANOLA MEAL PELLET TO FEEDLOT STEERS ON PERFORMANCE, RUMEN FERMENTATION, AND EATING BEHAVIOUR

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ABSTRACT

Two trials were conducted to evaluate effects of feeding barley/canola meal pellets on feedlot performance, subacute ruminal acidosis (SARA), and feeding behaviour in feedlot steers. In trial 1, 350 beef steers (285 ± 22 kg) were backgrounded and finished on pelleted barley and canola meal (PB) or rolled barley and canola meal (RB) diets. Backgrounding DMI was lower ($P < 0.05$) for PB steers but ADG did not differ ($P > 0.05$) and feed efficiency (FE) tended ($P < 0.1$) to be improved. During finishing and the total trial DMI and ADG were lower ($P < 0.05$) but FE was improved ($P < 0.05$) for the PB treatment. Steers fed PB were on feed longer ($P < 0.05$). Steers fed PB showed more variation in DMI ($P < 0.05$) than steers fed RB. Carcass composition and quality were similar between the treatments.

Trial 2 utilized 4 ruminally fistulated beef steers in a 4 x 4 latin square, 2 x 2 factorial trial. Factors were processing (pelleted vs. rolled) and grain type (barley vs. corn). All treatments included canola meal. Each 23 d period consisted of a 19 d adaptation period followed by a 24 h rumen fluid collection period, and a 24 h eating behaviour study. There were no grain type x processing interactions ($P > 0.05$) or effect of grain type ($P > 0.05$) on any of the variables. Eating behaviour did not differ ($P < 0.05$) between treatments. Processing had no effect ($P > 0.05$) on rumen ammonia or volatile fatty acid (VFA) concentration, proportion of acetate or butyrate, or rumen osmolality. Steers fed pelleted grain had lower ($P < 0.05$) rumen pH measurements, a greater ($P < 0.05$) molar proportion of propionate, and decreased ($P < 0.05$) acetate:propionate ratio. To reflect the feedlot trial corn was removed from the model. Rumen VFA concentration was higher ($P < 0.05$) and pH lower ($P < 0.05$) for the PB

steers. Results show performance during backgrounding was improved but finishing performance depressed in PB steers. Further research is necessary to reduce the risk of SARA when feeding PB during finishing.

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LIST OF ABBREVIATIONS

ADF	Acid Detergent Fibre
ADG	Average Daily Gain
ºC	Degrees Celsius
CLA	Conjugated Linoleic Acid
CP	Crude Protein
d	Day
DE	Digestible Energy
DHA	Docosahexanoic Acid
DIP	Dietary Intake Protein
DM	Dry Matter
DMI	Dry Matter Intake
EPA	Eicosapentanoic Acid
h	Hour
IBR	Infectious Bovine Rhinotracheitis
min	Minute
MUFA	Monounsaturated Fatty Acid
NDF	Neutral Detergent Fibre
NE_G	Net Energy of Gain
NE_M	Net Energy of Maintenance
NRC	National Research Council
P	Probability
PB	Pelleted Barley and Canola Meal Treatment

PI_3	Parainfluenza 3
PUFA	Polyunsaturated Fatty Acid
RB	Rolled Barley and Canola Meal Treatment
RDP	Rumen Degradable Protein
SARA	Subacute Ruminal Acidosis
SEM	Standard Error of the Mean
SFA	Saturated Fatty Acid
TDN	Total Digestible Nutrients
TM	Trace Mineral
TMR	Total Mixed Ration
VFA	Volatile Fatty Acid

1.0 INTRODUCTION

There has been recent interest by countries such as Japan in importing Canadian-grown feed barley. Beef from cattle finished in western Canadian feedlots is desirable in many foreign markets, such as Japan, because of the redness of the lean and the firm, white fat (Knight and Death 1997; Boles et al. 2004). Canadian feedlots typically finish cattle on high energy, high grain diets, and because of its high energy and crude protein content barley is commonly used in these diets (Bradshaw et al. 1996). Feeding barley leads to high gains, desirable feed efficiency, and the lack of carotenoid content in barley leads to the hard, white carcass fat that consumers find desirable (Brandt et al. 1992; Bradshaw et al. 1996; Boles et al. 2004). Currently, barley is not genetically modified, an aspect that is important to some consumers. It is because of this that foreign countries are interested in importing Canadian-grown feed barley. Unfortunately, due to local tariffs and high freight costs, exporting feed barley to these countries is not economically feasible. These countries also import protein sources, so development of a product utilizing feed barley as well as a protein source, such as canola meal, would be very advantageous for both Canada and the market to which this product is being sold.

Grain should be processed prior to feeding, as this increases the digestibility of the grain and also increases average daily gain (ADG) and improves feed efficiency (Bradshaw et al. 1996; Mathison 1996; Galyean and Rivera 2003). Processing also increases the bulk density of the grain, reducing shipping costs. Grinding and then pelleting barley with canola meal to increase the CP content is beneficial from an export perspective for a number of reasons. The increased processing reduces transportation costs, tariffs are reduced, and the product is high in both energy and protein and thus more valuable to the purchaser. Producing such a product would use feed grown in Canada and processing would take place

before export, therefore it would be a value-added product. Processing barley before shipping both would increase the digestibility of the grain, and result in a more economically feasible product.

Though processing grain can lead to increased performance, there are drawbacks to feeding grain which has been processed to a higher degree (i.e. to a smaller particle size than rolling). Grain which has been highly processed undergoes very rapid fermentation which can predispose cattle to metabolic disease (Owens et al. 1998). The metabolic disease of greatest interest to the feedlot industry is subacute ruminal acidosis. This disorder can lead to increased variation in DMI, reduced DMI, and reduced ADG (Owens et al. 1998; Yang et al. 2000). Physiologically, subacute ruminal acidosis results in accumulation of VFA, reduced rumen pH, and as a result osmolality as well as rumen ammonia concentration are often increased (Rémond et al. 1996; Nocek 1997; Krajcarski-Hunt et al. 2002). Ground grain is not commonly fed as the fine particle size of the feed increases the rate of digestion and therefore increases the risk of the problems described above. While feeding ground barley has been shown to decrease DMI, feed efficiency was not reduced to the same extent (Mathison 1981 as cited in Mathison 1996). If the reason behind the depressed DMI can be uncovered and corrected, feeding a ground grain product could become beneficial.

The objective of this review is to focus on the effects of feeding a highly processed barley and canola meal product to feedlot cattle on feedlot performance, subacute ruminal acidosis, and feeding behaviour. This thesis then tested the hypothesis that barley which has been ground and pelleted can be used to effectively background and finish feedlot cattle.

2.0 LITERATURE REVIEW

2.1 Cereal Grains in Feedlot Rations

In a typical North American feedlot, cattle are fed a high forage, low concentrate diet during the backgrounding or growing stage (Block et al. 2001; Bengochea et al. 2005). The purpose of this low energy diet is to control muscle and fat growth to allow for skeletal development (Block et al. 2001). Following backgrounding animals are gradually adapted to a high grain diet for the finishing phase (Owens et al. 1998). The purpose of this gradual adjustment is to allow the rumen microbes time to adapt to the high grain content of the diet, as this is the most common time for acidosis to occur (Goad et al. 1998; Owens et al. 1998). Diets fed during finishing are high in cereal grain concentrates because grain is a relatively cheap energy source compared to forage, and therefore a cheap way to increase the energy density of the diet (Huntington 1997).

The grain source is chosen based on availability and cost, as well as degree and cost of processing required (Owens et al. 1997). In North America two common grains fed to cattle are barley and corn. Since barley grows well across western Canada, it is a very important grain to the feedlot industry and is often used as the main energy source in feedlot diets (Bradshaw et al. 1996). Barley is high in energy (2.06 Mcal kg^{-1} NE_m; 1.40 Mcal kg^{-1} NE_g), as well as CP (13.2% CP) (NRC 1996). The barley seed is surrounded by a fibrous hull that has low digestibility because it is not damaged by chewing, although this hull is fermentable (Yang et al. 2000). The seed also has a tough pericarp which, if left intact, reduces digestibility of the seed, leading to reduced energy availability because of resistance of the pericarp to bacterial attachment (McAllister et al.

1994; Koenig et al. 2003). Within the pericarp is the starchy endosperm, which is very high in energy (McAllister and Cheng 1996).

Corn is high in energy (2.24 Mcal kg^{-1} NE_m; 1.55 Mcal kg^{-1} NE_g) but not as high in CP as barley (9.8% CP) (NRC 1996). The pericarp of corn is not nearly as tough and fibrous as the pericarp of barley, and unlike barley it can be disrupted by mastication alone (Yang et al. 2000). Barley has a faster rate of fermentation than corn (Owens et al. 1998). Corn has a relatively slow starch digestion rate, and up to 40% of the starch can escape ruminal fermentation and go on to be digested in the intestine (Ørskov 1986). This is because corn contains compact starch granules embedded within the kernel's horny endosperm, therefore the starch granules have less surface area available for microbial attachment (Owens et al. 1998; Zinn et al. 2002). In contrast, once the outer pericarp of the barley seed is disrupted, ruminal degradation and fermentation occurs more rapidly than in corn (McAllister et al. 1993; Yang et al. 2000; Foley et al. 2006; Rotger et al. 2006). Barley is considered to have a very high starch digestion rate, and at least 90% of the starch is fermented in the rumen (Ørskov 1986). The difference in starch digestion rate between barley and corn is due to differences in the physical composition of the grains. Corn has a protein matrix, with compact starch granules embedded in the starchy endosperm, therefore it is not readily solubilized and penetrated by bacteria like the starch of barley (Owens et al. 1998; Yang et al. 2000; Zinn et al. 2002).

Processing increases the digestibility of grain (Mathison 1996; Nocek 1997; Galyean and Rivera 2003). This is particularly true in barley, where once the pericarp is

cracked, ruminal degradation and fermentation occurs more rapidly than with corn (Yang et al. 2000). For cattle to utilize grain efficiently, it should be processed before feeding.

2.2 Grain Processing

Processing of grain is necessary to obtain optimal feed efficiency in the feedlot. Processing allows microbial access to the internal components of the grain because it breaks the outer pericarp and hull, increasing digestibility of the grain (Mathison 1996; Nocek 1997; Koenig et al. 2003). If whole instead of processed grain is fed, rates of gain can be depressed by 5 to 50% and the amount of feed required to achieve this gain is increased by as much as 15 to more than 100% (Mathison 1996). Also, if whole grain is fed, as much as 30% of it appears undigested in the feces (Ørskov 1986). More highly processed barley has a larger soluble fraction, smaller potentially degradable fraction, and an increased fractional rate of degradation when compared to unprocessed barley or barley processed to a lesser degree (Beauchemin et al. 2001). Bradshaw et al. (1996) found that processing barley had a positive effect on DM digestibility. They also found that animals fed processed barley had higher ADG and superior feed efficiency than cattle fed whole barley. However, processing grain too extensively also has its drawbacks. It can lead to very rapid and complete digestion resulting in accumulation of VFA and decreased pH (Ørskov 1986; Nocek 1997) both of which result in unfavourable conditions for microbial protein synthesis and fibre digestion (Koenig et al. 2003). The results of such research has lead to the goal of grain processing being to maximize the extent of carbohydrate digestion while controlling the rate of digestion (Koenig et al. 2003).

In industry, a rule of thumb used to be to process grain just enough to crack the outer hull, but lately there has been evidence suggesting that grain should be processed to a greater degree (Mathison et al. 1997). It is now recommended that there should be a maximum of 5% whole kernels present, by weight. It was thought that due to problems associated with feeding highly processed grain, it was better to have the kernels just cracked, with the possibility of whole kernels being present as opposed to over-processing with too many fines (Hironaka et al. 1979). However, evidence shows that greater processing can result in improved feed efficiency to the point that the negative consequences of over-processing are often outweighed, and are also less than the consequences of under-processing (Bradshaw et al. 1996; Mathison 1996; Mathison et al. 1997). While it would be desirable to suggest that no whole kernels be present in dry rolled grain, this is not practical due to the presence of fines that would result from over-processing (Mathison et al. 1997). It is instead recommended that dry rolled grain should not contain more than 5% whole kernels by weight (Mathison et al. 1997).

There are several different grain processing methods and within each of these methods processing can be done to varying degrees, from coarse to extensively processed. Three common methods of processing are tempering, steam flaking, and dry rolling. A fourth method that has been practiced and researched in the past is grinding. Tempering grain involves adding water to the grain and allowing this water to penetrate it before rolling (Mathison et al. 1997). There are several reasons why grain is tempered. It is believed it results in fewer fines and a more uniform particle size, produces less dust, creates an optimal dietary moisture content, and improves the nutritive value of the grain (Mathison et al. 1997). Results, however, have been varied. There are some reports that

tempering may improve performance (Mathison 1996). Wang et al. (2003) found that while tempering grain had no effect on ADG, DMI, or feed efficiency when compared to dry rolling during backgrounding, all were improved during finishing. Others have found no effect on performance (Bradshaw et al. 1996; Mathison et al. 1997).

Steam flaking refers to the practice of applying steam to the grain and then rolling it (Mathison 1996; Zinn et al. 2002). There are five production factors involved that can be controlled. These factors influence the quality of the steam flaked grain and include temperature, time steam is applied, roll corrugation, roll gap, and roll tension (Zinn et al. 2002). Steam flaking corn has been shown to improve digestibility (Huntington 1997; Cooper et al. 2002; Zinn et al. 2002). Steam flaking wheat and corn resulted in decreased DMI but not ADG, and feed efficiency was improved by 10% (Owens et al. 1997). With barley, however, steam flaking had no effect on ADG, DMI, or feed efficiency when compared to dry rolling (Owens et al. 1997) and starch digestibility was increased by less than 6% (Huntington 1997). Some researchers have found that if barley is steam flaked too finely both ADG and feed efficiency are actually depressed (Owens et al. 1997). In contrast, Zinn (1993) found no differences between flake thicknesses in ADG, DMI, or feed efficiency of cattle fed extensively processed steam flaked barley vs. barley steam flaked to a greater thickness. One benefit to steam flaking vs. dry rolling barley is that steam flaked barley can be more extensively processed without breaking the kernel (Mathison et al. 1997). Mathison (1996), summarizing the results of several trials, concluded that although data suggests the digestibility of barley is higher when it is steam flaked than when it is dry rolled, animal performance results do not support the cost and facilities required to process barley to this degree. Animal response to steam flaking with

regard to ADG and feed efficiency was minimal, and the feeding value of steam flaked barley is not improved over dry rolled barley. This lack of response means there is no advantage to steam flaking barley over simply dry rolling it (Mathison 1996).

Dry rolling is a relatively inexpensive and easy method of processing grain. Dry rolling grain increases ADG and improves feed efficiency when compared to feeding whole grain (Mathison 1996; Goonewardene et al. 1998). Dry rolling increases digestibility by 10 to 30% over whole barley (Mathison 1996). Dry rolling barley as opposed to feeding it whole has been shown to improve ADG by 19.6 and 9.1% in backgrounding and finishing cattle, respectively, and improved feed efficiency by 16.4 (backgrounding) or 13.1% (finishing) (Goonewardene et al. 1998). However, no beneficial effects on DMI, any carcass traits, or grade were noted (Goonewardene et al. 1998). As mentioned previously, there is no benefit to steam flaking barley over rolling it. However, when comparing dry rolled to steam flaked corn, steam flaking can decrease DMI without decreasing ADG significantly and therefore feed efficiency is actually improved (Owens et al. 1997). While results of tempering vary, in general there is no advantage to tempering barley over dry rolling when looking at cattle performance (Bradshaw et al. 1996; Mathison et al. 1997). Dry rolling is a relatively cheap and easy processing method. There is no strong evidence that further processing grain by tempering or steam flaking improves performance, therefore many western Canadian feedlots dry roll grain, particularly barley.

In rare instances ground grain is fed. Feeding ground grain has been researched in the past. Grinding greatly increases digestibility of the grain (Nocek 1997; Owens et al. 1997), but is typically avoided because it leads to decreased DMI and possible health

problems due to the dustiness of the feed and the increased incidence of fines (Zinn 1993; Mathison 1996; Beauchemin et al. 2001). Mathison (1981 as cited in Mathison 1996) found that steers fed ground barley had reduced ADG, reduced feed efficiency, and less fat when compared to steers fed rolled barley. Dry matter intake was depressed by 5%, and explained the reduced performance. One promising observation from this research is that while DMI was depressed by 5%, feed efficiency was only depressed by 1%, suggesting that DMI would not have to be increased to the level of rolled barley-fed steers for performance to be equal. Health problems associated with feeding ground grain include reduced rumen pH, acidosis, abnormal rumen papillae, rumenitis, and bloat (Cheng and Hironaka 1973; Hironaka et al. 1973; Hironaka et al. 1979). Other problems associated with feeding ground grain include inadequate saliva production to maintain a desirable rumen pH, and inadequate physical structure to stimulate rumen motility (Ørskov 1986). Ground grain lacks the fibrous structure required for tactile stimuli therefore leading to inadequate abrasion of rumen epithelium, the reason behind the reduced rumen motility (Ørskov 1986).

2.3 Effect of Feeding Highly Processed Cereal Grains to Cattle

While feeding grain processed to a small particle size has its benefits, there are drawbacks. Reduced DMI is often observed (Mathison et al. 1996; Owens et al. 1997; Beauchemin et al. 2001). The particle size reduction that results from processing makes starch more readily available, and therefore risk of metabolic disease is increased (Owens et al. 1998). The rapid fermentation of these grains results in increased production of VFA and decreased rumen pH and therefore can lead to metabolic disorders such as acute

acidosis, sub-acute ruminal acidosis (SARA), bloat, laminitis, and liver abscesses (Ørskov 1986; Narayanan et al. 1997; Yang et al. 2000; Beauchemin et al. 2001). These disorders can lead to variation in feed DMI and overall poor performance (Nocek 1997; Owens 1998; Krajcarski-Hunt et al. 2002). Another risk with feeding processed grain is that it may decrease the amount of time spent eating and ruminating and therefore may decrease saliva production, a very important source of rumen buffering capacity (Ørskov 1986). Grinding grain to a fine particle size can result in excess fines and dustiness which pose other problems such as reduced DMI (Beauchemin et al. 2001).

2.3.1 Ruminal Acidosis

Acidosis is a metabolic disorder often observed in feedlot cattle due to the high concentrate diets fed during finishing (Nocek et al. 1997; Nagaraja and Chengappa 1998; Owens et al. 1998; Galyean and Rivera 2003). The most common time for acidosis to occur is during adaptation to the high-grain diet (Goad et al. 1998; Owens et al. 1998). It is often identified by a drop in rumen pH and an increase in rumen organic acids such as lactate and VFAs (Krehbiel et al. 1995; Galyean and Rivera 2003). Acidosis results in physiological changes in the rumen that lead to several different systemic changes (Nocek 1997). In some cases these changes in the rumen can lead to systemic acidosis and can result in death (Nocek 1997). In ruminal acidosis, an increase in organic acids drives the rumen pH down, resulting in reduced rumen motility, stasis, rumenitis, and hyperkaratosis (Nocek 1997; Narayanan et al. 1997). These changes allow rumen microbes to escape through the rumen wall into the hepatic circulation where they can cause liver abscesses (Tan et al. 1994; Nocek 1997; Narayanan et al. 1997; Nagaraja and

Chengappa 1998; Nagaraja et al. 1999; Checkley et al. 2005). Lipopolysaccharides from gram-negative bacteria in the rumen may also escape into hepatic circulation leading to the production of proinflammatory cytokines and a systemic inflammatory response (Gozho et al. 2005; Gozho et al.2006; Gozho et al. 2007). The increased rumen osmolality resulting from the higher acid load may cause several other changes. Reduced extracellular volume can cause dehydration, decreased cardiac output, reduced peripheral perfusion, and reduced renal blood flow which may result in shock and ultimately, death (Nocek 1997). Secondary diseases caused by acidosis other than liver abscesses include rumenitis, laminitis and polioencephalomalacia (Krehbiel et al. 1995; Owens et al. 1998; Galyean and Rivera 2003). Long-term effects of acidosis can include decreased nutrient absorption due to rumen wall damage (Krehbiel et al. 1995; Owens et al. 1998). Decreased rumen absorption capacity results in reduced feed efficiency and therefore decreased performance (Krehbiel et al. 1995). The amount of rumen wall damage depends on the frequency and length of the acidotic challenge (Krehbiel et al. 1995).

Ruminal acidosis is the name for a range of metabolic disturbances that form a continuum from acute to chronic, or subacute (Krehbiel et al. 1995). Symptoms can range from temporarily depressed DMI to death (Krehbiel et al. 1995). An animal is considered to be acidotic when rumen pH reaches 5.6 or lower (Krehbiel et al. 1995). Other signs of rumen acidosis include increased serum concentrations of acute phase proteins such as serum amyloid-A and haptoglobin (Gozho et al. 2005; Gozho et al. 2006; Gozho et al. 2007).

2.3.1.1 Acute vs. Sub-Acute Ruminal Acidosis

Acute acidosis results when organic acids in the rumen accumulate, resulting in a drastic increase in rumen acidity and osmolality and a large decrease in total rumen protozoa (Ørskov 1986; Nocek 1997; Owens et al. 1998). It begins with an increase in VFA production and concurrent decrease in VFA absorption, further increasing VFA concentration and reducing pH (Ørskov 1986; Krehbiel et al. 1995; Nocek 1997; Brown et al. 2000). Also occurring is an increase in lactic acid concentration. The number of lactate-producing microbes increases because they are tolerant to low pH, and lactate-utilizing microbes, which are typically sensitive to low pH, decrease resulting in the accumulation of lactic acid (Nocek 1997; Owens et al. 1998; Galyean and Rivera 2003). Acute acidosis can result in death if the damage to the intestinal wall is great enough and metabolic acidosis sets in (Nocek 1997; Owens et al. 1998). Acute acidosis has been defined as a state where rumen pH is 5.0 or lower for a period of time (Nocek 1997). If an animal is suffering from acute acidosis they show overt signs of illness, including anorexia, lethargy, and diarrhea (Nocek 1997; Owens et al. 1998).

Sub-acute ruminal acidosis is a common metabolic disease that temporarily alters rumen metabolism by causing low rumen pH, impaired microbial function, and changes in fermentation patterns (Nocek 1997; Krajcarski-Hunt et al. 2002). It is similar to acute acidosis, but unlike acute acidosis lactate levels generally remain unchanged and pH is not decreased to as great an extent (Nocek 1997; Goad et al. 1998; Galyean and Rivera 2003). Instead the change in pH is due almost solely to increased VFA concentration (Nocek 1997; Goad et al. 1998; Owens et al. 1998; Galyean and Rivera 2003). Since SARA is often a result of attempting to maximize energy intake, it often occurs in well-

managed, high-producing dairy herds (Nocek 1997), and is common in high-performing cattle in the feedlot (Smith 1998). While an animal suffering from acute acidosis may show overt symptoms as a result of decreased rumen pH after consumption of readily fermentable carbohydrates, cattle with SARA can continue throughout the entire feeding period without the animal appearing sick (Nocek 1997; Owens et al. 1998). Some known causes of SARA are a rapid increase in dietary levels of concentrate, excess feeding of concentrate, or inadequate rumen buffering (Owens et al. 1998; Krajcarski-Hunt et al. 2002; Galyean and Rivera 2003). It has been defined as a state where the pH of the rumen drops below 5.6 for prolonged periods of time (Krehbiel et al. 1995). The best indicator of SARA in the feedlot setting is variation in DMI (Nocek 1997; Owens et al. 1998; Galyean and Rivera 2003). Variation in DMI is related to the decrease in pH (Fulton 1979; Nocek 1997). Cattle that experience SARA due to low rumen pH will decrease DMI dramatically until they recover in a few days. At this time they go back on feed, overeat, and as a result rumen pH drops and they go off of feed again (Fulton et al. 1979). The variation in DMI results in decreased DMI throughout the feeding period, and often leads to poor overall performance (Owens et al. 1998; Galyean and Rivera 2003). A second contributing reason for this poor performance is due to decreased VFA absorption from the rumen wall. Over time SARA can lead to damage of rumen papillae and thus decreases VFA absorption. This leads to reduced metabolic efficiency and poor gains (Krehbiel et al. 1995). Sub-acute ruminal acidosis leads to decreased appetite and feed DMI, as well as variation in DMI (Nocek 1997; Krajcarski-Hunt et al. 2002; Galyean and Rivera 2003). In the feedlot setting, this means cattle are not performing as well as they should. It may also lead to diarrhea and lameness (Nocek 1997; Owens et al.

1998). In a study by Krajcarski-Hunt et al. (2002) it was found that the induction of SARA caused a significant decrease in mean daily rumen pH, a significant increase in the daily time rumen pH was below 6 and 5.6, and a significant decrease in DMI. Induction of SARA also led to reduced NDF digestibility of forage. Not only is the animal eating less, but it is getting less out of the feed it is consuming.

Animals suffering from SARA often have a higher ruminal VFA concentration (Krehbiel et al. 1995; Nocek 1997; Owens et al. 1998; Galyean and Rivera 2003). This can be due to increased VFA production, decreased absorption, or a combination of the two (Krehbiel et al. 1995; Nocek 1997). The decrease in absorption may be due to a variety of factors. For example, a decrease in blood flow to the gastrointestinal tract due to SARA, and the physiological changes in the gastrointestinal tract as a result of feeding high grain diets, have both been shown to decrease VFA absorption (Nocek 1997).

2.3.1.2 Factors Affecting Incidence of Acidosis

The etiology of acidosis is very complex. Several different factors affect the incidence of acidosis. Several of these factors interact with each other (Galyean and Eng 1998; Galyean and Rivera 2003) (Figure 2.1). Some known causes of SARA are rapid increases in dietary levels of concentrate, excess feeding of concentrate, and inadequate rumen buffering (Krajcarski-Hunt et al. 2002). These can be prevented by following good bunk management practices, particularly with regards to ration formulation and feed delivery (Nocek 1997).

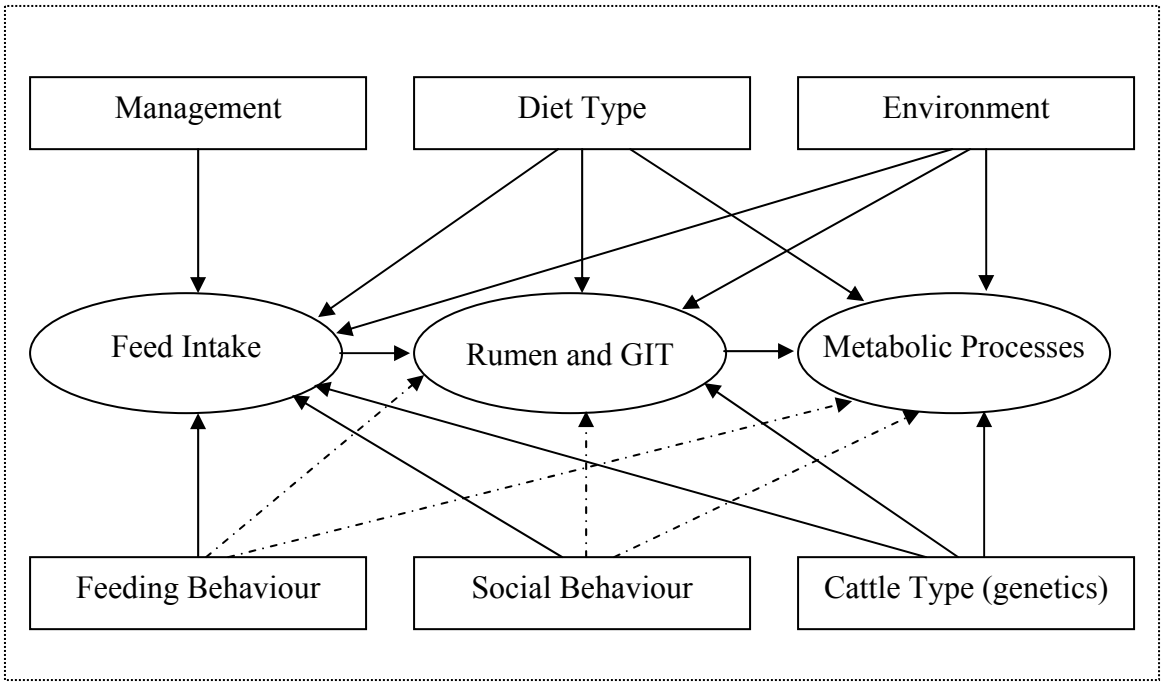

Figure 2.1. Various factors, and their inter-relationships, affecting the incidence of subacute ruminal acidosis. Solid lines represent relationships known to exist while broken lines represent proposed relationships. From Galyean and Rivera 2003.

Cattle on high grain diets are at a greater risk of SARA than those on low grain diets (Owens et al. 1998). Roughage lowers the fermentable carbohydrate content of the diet, reduces meal size, and increases the amount of buffer reaching the rumen by stimulating chewing and thus saliva flow (Owens et al. 1998; Galyean and Rivera 2003). However, while this will reduce potential for SARA, it often results in poor performance and reduced economic efficiency, so high grain diets are often fed regardless (Owens et al. 1998). This makes bunk management even more important. To prevent SARA caused by rapid increases in dietary levels of concentrate, feedlot managers will adapt cattle to the high grain diet by feeding a number of different diets with increasing levels of concentrate over a period of several days (Galyean and Rivera 2003; Bevans et al. 2005). This gives rumen microbes time to adapt to the new diet. Variation in day-to-day DMI can lead to SARA (Owens et al. 1998; Erickson et al. 2003; Galyean and Rivera 2003). Care must be taken to ensure that DMI is controlled during this adaptation period. Unfortunately in large pens of cattle there are large swings in individual DMI therefore this is a particularly high-risk period (Galyean and Rivera 2003). One practice sometimes used during adaptation and throughout feeding is limit feeding. Some researchers have found that this reduces the incidence of SARA (Owens et al. 1998; Galyean and Rivera 2003). However, there is the risk that under this feeding regimen certain individuals within a pen will have severely restricted DMI at times, and will consume more feed at a more rapid rate following these times of restriction (Erickson et al. 2003). This is the reason that under either limit or *ad libitum* feeding systems timid animals are sometimes more prone to SARA (Owens et al. 1998). Delivering feed more

than once a day can allow more opportunity for these timid animals to access feed and reduces the incidence of SARA.

Delivery of feed is important in preventing SARA. Anything that delays the delivery or timing of meals can lead to over-eating and should therefore be avoided. Cattle processing should be timed so a delay in feeding does not occur (Owens et al. 1998). If this is not possible, it may be a good idea to restrict intake at the next feeding to avoid over-eating (Owens et al. 1998). An inconsistent amount of feed delivered can increase severity of SARA (Schwartzkopf-Genswein et al. 2004). When increasing the amount of feed delivered to a pen, all changes should be made slowly and not at the same time dietary levels of concentrate are being increased. Since increased processing of grain increases the risk of acidosis, stricter bunk management is required when feeding highly processed grains (Nocek 1997; Owens et al. 1998; Galyean and Rivera 2003).

Other practices have been shown to reduce the potential for SARA. Estrogenic implants reduce the risk of SARA because they increase meal frequency (Owens et al. 1998). The addition of buffers such as sodium bicarbonate to the diet helps buffer the rumen, preventing SARA (Thoefner et al. 2004). Other feed additives have been shown to prevent SARA. An ionophore such as monensin can decrease daily variation in DMI, reduce daily DMI, increase meal frequency while reducing meal size, and inhibit lactate-producing bacteria (Stock et al. 1995; Owens et al. 1998). These taken together can reduce the risk of SARA. It is important to remember, however, that even when rations are formulated to reduce SARA and proper bunk management is practiced, some animals may still suffer from SARA. There is a wide animal-to-animal variation in capacity to handle rumen acid loads (Brown et al. 2000).

2.3.2 Laminitis

Pododermatitis aseptic diffusa, more commonly known as laminitis, is a disorder affecting the feet of ruminants, ungulates, and equids (Nocek 1997; Thoefner et al. 2004). It is an asceptic inflammation of the dermal layers of the interior of the foot (Nocek 1997). It occurs in acute, subclinical, and chronic forms, and may result in permanent anatomical damage (Nocek 1997). Symptoms may include extreme pain, swelling and heat above the coronary band, sole hemorrhages and yellow discoloration, double soles, heel erosion, dorsal wall concavity, and ridging of the dorsal wall (Nocek 1997). The etiology of laminitis involves the interaction of several factors, but nutritional management is a major component as laminitis is often secondary to acidosis (Nocek 1997; Thoefner et al. 2004). Decreased rumen pH leads to changes in the pathogenesis of the rumen, liver, and gastrointestinal tract and predisposes animals to laminitis (Nocek 1997). Decreased ruminal pH, bacteriolysis, and tissue degradation result in the release of the vasoactive substances histamine and endotoxins, thought to cause laminitis (Nocek 1997; Thoefner et al. 2004). Vasoconstriction and dilation result from the release of these vasoactive substances, and this destroys the microvasculature of the corium (Nocek 1997). Ischemia results, causing a subsequent reduction in the oxygen and nutrients reaching the extremities of the corium and damage to tissues critical for locomotion (Nocek 1997). Since laminitis is initiated by a decrease in rumen pH, measures taken to prevent ruminal acidosis should also reduce the risk of laminitis. Factors increasing the risk of acidosis, such as feeding high levels of highly processed grain, may increase the risk of laminitis.

2.3.3 Rumenitis and Liver Abscesses

High rumen acid load, such as that which may occur as a result of feeding highly processed grain can result in rumenitis (Ørskov 1986; Narayanan et al. 1997; Nagaraja and Chengappa 1998). Rumenitis is an infection of the rumen wall that results in damage to the wall with clumping and necrosis of ruminal papillae often observed (Ørskov 1986; Nagaraja and Chengappa 1998). During rumenitis the wall is often further damaged by foreign objects in the feed, sharp feed particles, and cattle hairs becoming embedded in the rumen epithelium (Ørskov 1986; Nagaraja and Chengappa 1998). The integrity of the rumen wall is compromised as ruminal lesions result (Nagaraja and Chengappa 1998). Opportunistic bacteria, such as *Fusobacterium necrophorum* invade and colonize the ruminal lesions and gain entry into the portal bloodstream and liver abscesses result (Nocek 1997; Narayanan et al. 1997; Nagaraja and Chengappa 1998; Galyean and Rivera 2003).

Liver abscesses are a problem of economic concern in feedlot cattle. While they are found in all ages and breeds of cattle, they are most commonly associated with feedlot cattle fed high grain diets (Brink et al. 1990; Nagaraja and Chengappa 1998; Nagaraja et al. 1999). The economic impact of liver abscesses are several-fold, the most obvious being the economic consequences of carcass quality defects such as down-grades and liver condemnations at slaughter (Checkley et al. 2005). In 1998/1999, these defects resulted in estimated losses of $2.66 CDN per head to the Canadian industry (Van Donkersgoed et al. 2001). Other problems experienced in the slaughter plant due to liver abscesses include the requirement for excess trimming of the carcass because of adhesion of the abscess to the surrounding organs, or possibly condemnation of the entire viscera

(Nagaraja and Chengappa 1998). If the abscess ruptures it can contaminate the carcass, interrupting flow along the slaughter line and costing the plant time and money (Nagaraja and Chengappa 1998).

Of even greater economic impact, however, is the depression in animal performance and carcass yield that often accompany liver abscesses. Studies have shown that severe liver abscesses can lead to decreased DMI, reduced ADG, reduced feed efficiency, and reduced carcass weight and dressing percentage (Brink et al. 1990; Nagaraja and Chengappa 1998; Smith 1998; Galyean and Riveray 2003). In fact, liver abscesses may decrease feed efficiency and ADG by as much as 9.7 and 11%, respectively (Brink et al. 1990). It appears the reduction in DMI was responsible for this reduction in ADG and feed efficiency (Brink et al. 1990).

The top two etiological agents associated with liver abscesses are *Fusobacterium necrophorum* and *Actinomyces pyogenes*, respectively (Tan et al. 1994; Narayanan et al. 1997; Nagaraja and Chengappa 1998; Checkley et al. 2005). *F. necrophorum* is considered a primary invader (Tan et al. 1994; Narayanan et al. 1997; Nagaraja and Chengappa 1998; Nagaraja et al. 1999; Checkley et al. 2005). The role of *A. pyogenes* is not clear. However it is generally accepted that this organism helps *F. necrophorum* colonize the liver, since *A. pyogenes* is almost always associated with *F. necrophorum* in liver abscesses (Nagaraja et al. 1999). There is a theory that a synergistic relationship exists between the 2 microbes (Nagaraja et al. 1999). Nagaraja et al. (1999) also isolated *F. necrophorum* from all liver abscesses studied. In other studies, the presence of this bacteria in liver abscesses ranged from 81 to 100% (Nagaraja and Chengappa 1998). Both of these microbes have also been isolated from ruminal contents and ruminal walls

of slaughtered feedlot cattle, as well as from abscessed livers (Narayanan et al. 1997). Ribotyping of *F. necrophorum* and *A. pyogenes* isolates from liver abscesses, rumens, and rumen walls suggest that these bacteria originate from the rumen and rumen wall (Narayanan et al. 1997), supporting the hypothesis that lesions in the rumen wall allow these bacteria to reach the liver and cause abscesses. The theory is that acidotic conditions can lead to rumenitis resulting in rumen lesions (Narayanan et al. 1997; Nocek 1997; Nagaraja and Chengappa 1998; Nagaraja et al. 1999; Galyean and Rivera 2003). Microbes escape the rumen through these lesions into the hepatic portal circulation where they are filtered by the liver (Narayanan et al. 1997; Nagaraja and Chengappa 1998; Nagaraja and Chengappa 1998). They then colonize the liver resulting in abscesses (Nagaraja and Chengappa 1998; Narayanan et al. 1999). The resulting abscess can be very small (<1 mm) or as great as 15 cm (Nagaraja and Chengappa 1998). Typically, the incidence of liver abscesses in North American feedlot cattle ranges from 12 to 32% (Brink et al. 1990).

Since liver abscesses are not easily detected in a living animal, prevention is the best approach (Galyean and Rivera 2003). There are several factors predisposing cattle to liver abscesses. Since liver abscesses are closely associated with acidosis, diet is the major factor (Narayanan et al. 1997, Nagaraja and Chengappa 1998; Nagaraja et al. 1999; Galyean and Rivera 2003). Incidence of liver abscesses increase as dietary forage decreases (Brink et al. 1990; Nagaraja and Chengappa 1998; Galyean and Rivera 2003). Grain type has an impact on incidence as rapidly fermented grains such as wheat, barley, and high moisture corn can lead to fluctuations in pH and DMI, predisposing the animal to acidotic conditions in the rumen and therefore to rumenitis and liver abscesses (Nocek

1997; Beauchemin et al. 2001; Galyean and Rivera 2003). The same goes for increased grain processing (Nagaraja and Chengappa 1998). Since bacteria are causative agents of liver abscesses, the inclusion of antibiotics in the diet can decrease incidence (Nagaraja and Chengappa 1998; Nagaraja et al. 1999; Galyean and Rivera 2003; Checkley et al. 2005). There are currently 5 antibiotics approved for prevention of liver abscesses in feedlot cattle listed in the "Feed Additive Compendium" (1998): bacitracin methylene disalicylate, chlortetracycline, oxytetracycline, tylosin, and virginiamycin, with tylosin being the most effective (Nagaraja et al. 1999, Galyean and Rivera 2003). In fact, tylosin has been shown to reduce incidence of liver abscesses by 40 to 70% (Nagaraja and Chengappa 1998).

Another important factor regarding liver abscesses is time on feed. Holsteins generally take longer to finish, and they also have a higher incidence of liver abscesses (Nagaraja and Chengappa 1998). When comparing steers and heifers, heifers typically consume less, finish out more quickly, and also have a lower incidence of liver abscesses (Nagaraja and Chengappa 1998). Limit feeding cattle has also been shown to increase the incidence of acidosis and as a result, that of liver abscesses (Loerch 1990, Cooper et al. 1999). Liver abscesses are very closely related to rumen acidosis (Narayanan et al. 1997; Nagaraja and Chengappa 1998; Nagaraja et al. 1999) and so the same steps taken to reduce acidosis will also reduce incidence of liver abscesses. Therefore, proper bunk management can be an important tool in reducing the occurrence of liver abscesses.

2.3.3.1 Measuring Liver Abscesses

One way to gauge severity of liver abscesses and to compare liver abscesses between cattle is to score the liver following slaughter. There are several different scoring systems used. A system developed by the pharmaceutical industry (Elanco Animal Health, Division Eli Lilly Canada, Inc.) and used by other researchers (Brink et al. 1990; Nagaraja and Chengappa 1998; Checkley et al. 2005) uses a scale ranging from 0 to A+. A score of 0 represents a normal liver free of any abscesses. A score of A- represents a liver that has the presence of one to two small abscesses or abscess scars. A score of A indicates the liver has two to four abscesses typically under 25 mm in diameter. The A+ score is reserved for livers having one or more large active abscesses present that may either be visible on the surface or buried internally. A similar scale was used by McKinnon et al. (1992) where a numerical scale ranging from 0 to 3 was used. Livers with a score of 0 were free of abscesses, 1 represented livers with one small abscess, a score of 2 was given to livers with two to four small to medium abscesses, while livers showing one or more large abscesses or greater than four small to medium abscesses were given a score of 3.

2.4 Rumen Fermentation Parameters

2.4.1 Rumen pH

Rumen pH is a good indicator of rumen health and function. As carbohydrates are fermented in the rumen organic acids such as VFA and lactate are produced (Ørskov 1986; Owens et al. 1998; Beauchemin et al. 2003a). If acid production is greater than acid absorption, rumen pH will drop (Ørskov 1986; Krehbiel et al. 1995; Nocek 1997;

Brown et al. 2000). An accumulation of lactate exacerbates the decrease in rumen pH, as lactate-utilizing bacteria are very pH sensitive while lactate-producers are tolerant of a very acidic environment (Nocek 1997; Owens et al. 1998; Galyean and Rivera 2003). As mentioned previously, low rumen pH can lead to ruminal acidosis and therefore reduced performance. Physiologically, the primary indication that an animal is suffering from acidosis is decreased rumen pH (Krehbiel et al. 1995; Nocek 1997).

A depressed rumen pH can have adverse effects on digestion. Low rumen pH can lead to impaired microbial function (Krajcarski-Hunt et al. 2002) which can lead to decreased microbial protein synthesis (Russell and Wilson 1996; Bach et al. 2005). Fibre digestion has also been shown to be reduced with low rumen pH environments (Koenig et al. 2003).

Change in rumen pH is often dictated by rumen fermentation, as fermentation results in acid production and a subsequent drop in rumen pH (Allen 1997; Beauchemin et al. 2003a). As such, rumen pH follows a fairly predictable diurnal pattern. Rumen pH decreases following a meal then goes through a recovery period, rising until the next feeding (Koenig et al. 2003; Bevans et al. 2005; Rotger et al. 2006).

Processing grain increases the surface area of the grain, and also exposes the internal structures of the grain which allows more opportunity for microbial attachment (Koenig et al. 2003). This increases the rate and extent of digestion of processed grain vs. whole grain (Ørskov 1986; Nocek 1997; Galyean and Rivera 2003). Feeding highly processed grain results in reduced rumen pH (Marshall et al. 1992; Yang et al. 2000; Beauchemin et al. 2001). Barley grain is more rapidly fermented in the rumen than corn (McAllister et al. 1993; Foley et al. 2006; Rotger et al. 2006) and therefore it would be

assumed that barley-fed cattle would have lower rumen pH measurements when compared to corn-fed cattle. While some researchers found this to be true (Overton et al. 1995), others did not (Casper et al. 1999; Foley et al. 2006; Rotger et al. 2006). However, Casper et al. (1999) and Foley et al. (2006) were feeding medium concentrate dairy rations, and in both cases the corn was processed to a greater extent than barley, which could account for the lack of grain type effect on rumen pH.

2.4.1.1 Rumen Buffering via Saliva

Nearly half of the buffering of acids produced during rumen fermentation is provided by saliva (Allen 1997; Owens et al. 1998). Since chewing produces more saliva, more chewing results in greater buffering capacity (Campbell et al. 1992). Time spent chewing has been used as a way to gauge rumen health because of its effect on saliva secretion (Maekawa et al. 2002a). However, it has recently been discovered that increased time spent chewing does not always increase total saliva secretion as increased eating and ruminating was shown to be negatively correlated with resting saliva production (Maekawa et al. 2002a). Similarly, it was thought that due to the buffering capacity of saliva, chewing time was positively correlated with rumen pH. However it was recently shown that this was not the case (Beauchemin et al. 2003b). Yang and Beauchemin (2006a) discovered that increased chewing and increased saliva production are not always able to fully neutralize rumen pH. This helps explain the results of Marshall et al. (1992) and Campbell et al. (1992) who fed steers rolled or ground grain diets, and found that while rumen pH was lower for steers fed ground grain, chewing time did not differ between the two groups. It is therefore important to remember that

chewing times can remain similar even if rumen pH differs, and an increase in time spent chewing will not always result in an increase in rumen pH.

Diet can affect saliva production and minutes spent eating and ruminating in a day. Ørskov (1986) found that ground grains did not stimulate saliva production. Total chewing time increased with increasing silage level in the diet (Maekawa et al. 2002a) and with increasing dietary peNDF (Yang and Beauchemin 2006b). Roughage is known to stimulate chewing, so overall a high-forage diet will cause an animal to chew longer than a high-grain diet (Galyean and Rivera 2003).

2.4.2 Volatile Fatty Acid Concentration and Profile

The rumen functions as a fermentation vat. The fermentation of carbohydrates occurring in the rumen yields ATP that provides energy for rumen bacteria (Van Houtert 1993; Nocek 1997). Due to the anaerobic nature of the rumen, the fermentation yields VFA (Van Houtert 1993; Allen 1997). In ruminants the majority of energy used for maintenance and productive functions is provided by VFA (Allen 1997). The main VFA formed in the rumen during fermentation are acetate, propionate, and butyrate (Van Houtert 1993; Allen 1997).

Rumen conditions, such as pH and the nature of the substrate influence which VFA will be produced and by what pathway by altering the activities of certain groups of ruminal microorganisms (Van Houtert 1993). During fermentation of carboydrates, intermediate monomers are formed and all of these are catabolized to pyruvate (Van Houtert 1993). Several different pathways, each influenced by intracellular enzymes

produced by microorganisms, are used to convert the pyruvate to end products, the majority of which are acetate, propionate, and butyrate (Van Houtert 1993).

The pKa values of acetate, propionate, and butyrate are 4.75, 4.87, and 4.91, respectively. If the rumen pH is higher than the pKa of these acids then most will be present in the dissociated form, while if it is lower most will be present in the undissociated form (Rémond et al. 1996). As rumen pH decreases, VFA absorption has been shown to increase (Dijkstra et al. 1993). Therefore, undissociated VFA are more readily absorbed across the rumen wall than dissociated ones. Often, however, as rumen pH declines, an increase in rumen VFA concentration is observed (Allen 1997; Nocek 1997; Galyean and Rivera 2003). This could be caused by rate of production being greater than rate of absorption. Absorption may also be depressed during periods of low pH due to several reasons such as changes to the gastrointestinal tract that decrease absorptive capacity, like the decreased bloodflow to the gastrointestinal tract sometimes observed during SARA (Nocek 1997).

Marshall et al. (1992) found that processing barley had an effect on VFA concentration. Steers fed ground barley exhibited higher VFA concentrations than those fed rolled barley at 1 to 4 and 6 to 12 h post-feeding. In the same trial, there was also a greater depression in rumen pH over time in steers fed ground barley. Research comparing the VFA load of cattle fed corn vs. barley has resulted in more variable results. Some research has shown a difference in rumen VFA concentration between barley and corn-fed cattle (Casper et al. 1999; Khorsani et al. 2001) while others found no difference (Foley et al. 2006; Rotger et al. 2006).

Rumen pH impacts concentration of NAD^+ relative to NADH in the rumen, and changing the proportion of one relative to the other can alter the VFA profile. A neutral rumen pH results in a high NAD^+:NADH ratio. Therefore when animals are fed a forage-based diet the ratio is high, and flow rate of carbohydrate to pyruvate is decreased and acetate production is favoured (Van Houtert 1993). When production of acetate is favoured, there is a low rate of carbon flow throughout the pathways that produce propionate and butyrate (Van Houtert 1993). Both the propionate and butyrate pathways require the donation of an electron from NADH, so these pathways are favoured when the NAD^+:NADH ratio is low, such as would be the case when a high grain diet is fed (Van Houtert 1993). A ruminant fed a rapidly fermentable feed will produce more propionate relative to acetate, and butyrate production will also be increased. This effect has been observed in cattle fed extensively processed grain diets as well (Yang et al. 2000; Beauchemin et al. 2001; Čerešňáková et al. 2005).

In the rumen of grain fed cattle, 48 to 56%, on a molar basis, of the total VFA is acetate (Pylot et al. 2000; Ghorbani et al. 2002; Beauchemin et al. 2003a; Bevans et al. 2005). The majority of acetate passes through the rumen wall and enters the portal circulation (Van Houtert 1993). Once at the liver, acetate is the only of the 3 major VFA that is not significantly metabolized by the liver and of the small amount that does get metabolized, some is oxidized to carbon dioxide while the majority is used in anabolic processes (Van Houtert 1993). The main metabolic site for acetate is the peripheral tissues, where about 75% of acetate absorbed across the rumen wall is used (Bergman and Wolff 1971). The plasma concentration of acetate is fairly low because the peripheral tissue metabolizes this acid so quickly (Van Houtert 1993). In non-lactating

ruminants, muscle and adipose tissue are the major tissues utilizing acetate with the function being mainly oxidation and fat synthesis (Van Houtert 1993).

Propionate concentration in the rumen of grain-fed animals is typically 25 to 42% of the total rumen VFA (Ghorani et al. 2002; Beauchemin et al. 2003a; Szasz et al. 2005; Jaeger et al. 2006). There are 2 major pathways that form propionate in the rumen. It appears diet determines which pathway will dominate, as the randomizing pathway is the major pathway for production in roughage fed animals while the non-randomizing pathway dominates in ruminants fed high levels of concentrate (Van Houtert 1993). Very little propionate is metabolized in the rumen epithelium; the main organ for propionate metabolism is the liver, where it is the main substrate for the production of glucose, an important energy source in ruminants, via gluconeogenesis (Van Houtert 1993). In roughage fed animals nearly all of the propionate reaching the liver is metabolized, but in grain-fed animals more propionate may be absorbed across the rumen than the liver can metabolize, in which case an appreciable amount reaches the peripheral tissues (Van Houtert 1993).

Butyrate is the major VFA present in the lowest proportion, typically 8 to 16% of the total VFA in grain-fed cattle (Beauchemin et al. 2003a; Koenig et al. 2003; Szasz et al. 2005). The majority of butyrate is metabolized by the epithelium of the rumen and omasum, with upwards of 90% of all butyrate being used by these tissues (Bergman and Wolff 1971). It is also metabolized into the ketone bodies acetoacetate and ß-hydroxybutyrate (Van Houtert 1993). Ketone bodies cannot be used efficiently by the liver of ruminants. Thus any surplus not used to meet the energy requirements of the

rumen epithelium is used as an energy source for other extra-hepatic tissues (Van Houtert 1993).

Feeding highly processed barley leads to an increased level of propionate in the rumen (Yang et al. 2000). Feeding extensively processed barley reduced the molar percentage of acetate but increased that of propionate which resulted in a large decrease in the acetate:propionate ratio (Yang et al. 2000). A high level of propionate, as opposed to acetate and butyrate, places more energy towards weight gain and fat deposition. While this is not desirable for a dairy animal as it leads to lower milk fat it is beneficial to a feedlot animal (Beauchemin et al. 2003a). Researchers found no effect of grain type on VFA profile or acetate:propionate ratio when feeding cattle barley vs. corn-based diets (Foley et al. 2006; Rotger et al. 2006).

2.4.3 Rumen Osmolality

Rumen osmolality is a measure of the dissolved solutes in the rumen fluid (Owens et al. 1998). The main solutes are minerals, VFA, lactate, and glucose (Owens et al. 1998). On a concentrate diet, normal ruminal osmolality is between 260 to 355 mOsm L^{-1} (Owens et al. 1998; Brown et al. 2000; Bevans et al. 2005). Under acute acidotic conditions, values as high as 515 mOsm L^{-1} have been reported (Owens et al. 1998). High rumen osmolality exacerbates depressed rumen pH as it decreases the rate of acid absorption (Owens et al. 1998). When rumen osmolality is higher than blood osmolality, fluid from blood transfers into the rumen to neutralize acidotic conditions and regain the balance between systemic and rumen systems (Nocek 1997; Owens et al. 1998). This rapid influx can swell rumen papillae and rupture them (Owens et al. 1998). This causes

damage to the rumen wall and may allow rumen microbes responsible for liver abscesses to escape into the portal bloodstream (Nocek 1997; Nagaraja and Chengappa 1998; Nagaraja et al. 1999; Checkley et al. 2005). Areas where the rumen wall has been damaged in such a fashion can be permanently damaged and VFA absorption can be impacted (Nocek 1997; Owens et al. 1998). As such the effects of high rumen osmolality can be felt for a long time after the initial occurrence, both through liver abscesses and parakeratosis (thickening of the rumen wall).

2.4.4 Rumen Ammonia Concentration

Rumen ammonia levels are important because ammonia is used by a variety of rumen bacteria species as a building block for essential and non-essential amino acids during microbial protein synthesis (Eschanlauer et al. 2002; Bach et al. 2005). Rumen nitrogen metabolism can influence rumen ammonia concentration. There are two aspects critical to rumen nitrogen metabolism: 1) protein degradation where the protein is broken down to ammonia, peptides, and amino acids to provide a nitrogen source for the bacteria, and 2) the integration of these into microbial protein during microbial protein synthesis (Bach et al. 2005). If the rate of protein degradation is greater than that of microbial protein synthesis or carbohydrate fermentation, or if rumen degradable protein (RDP) is in excess of the amount required for microbial protein synthesis, the protein is degraded to ammonia which can accumulate in the rumen (Bach et al. 2005). An accumulation of rumen ammonia is considered an inefficiency, as excess ammonia is absorbed into the portal bloodstream, transported to the liver, turned into urea, and conveyed to the peripheral circulation (Eschanlauer et al. 2002; Bach et al. 2005). While

some of this urea is retained and recycled, some is excreted through the kidney (Bach et al. 2005). Once excreted, it is no longer available for integration into microbial protein.

For efficient microbial protein synthesis to occur, a carbohydrate source must be available for fermentation simultaneously with degraded protein because the carbohydrate is the energy source that drives microbial protein synthesis (Coppock 1973; Bach et al. 2005). Since microbial protein synthesis relies on the presence of carbohydrates to provide the energy to make peptide bonds, if the rate of carbohydrate fermentation exceeds protein degradation rate, energy is present but nitrogen is not therefore microbial protein synthesis declines (Nocek and Russell 1988). However, if protein degradation rate exceeds carbohydrate fermentation rate, ammonia can accumulate in the rumen (Nocek and Russell 1988). Cattle diets must include carbohydrate and protein sources that have similar degradation rates so energy can be captured for efficient microbial protein synthesis, and ammonia does not accumulate in the rumen.

Altering dietary concentrate level can influence rumen ammonia concentration. Different microbes prefer different nitrogen sources. For example, cellulolytic bacteria use ammonia nitrogen as their main nitrogen source, while amylolytic bacteria use ammonia, peptides, and amino acids as nitrogen sources (Russell et al. 1992). Roughly 66% of bacterial protein is derived from peptides and amino acids, with the rest coming from ammonia (Russell et al. 1983). When microbes show preferential use of peptides and amino acids for protein synthesis, ammonia will accumulate in the rumen (Bach et al. 2005).

Physical structure of plants may alter nitrogen metabolism. Protein in plants may not be easily accessible due to the fibre matrix in some plants (Bach et al. 2005). The matrix must be degraded before proteases and proteolytic bacteria can access the proteins (Bach et al. 2005). This means protein degradation does not just require proteolytic bacteria and enzymes, but also cellulolytic bacteria. The structure of barley and corn differs with regards to the protein matrix of the endosperm. That of corn has actually been shown to hinder access by rumen bacteria (McAllister 1991). This may be one explanation why barley has been shown to exhibit a higher rate of microbial protein synthesis than corn (Casper et al. 1999). The effect of grain type (corn vs. barley) on rumen ammonia concentration has been variable. In dairy cattle, barley-fed cattle had lower concentrations of rumen ammonia than corn-fed cattle (Casper et al. 1999). In beef cattle fed high grain diets rumen ammonia concentration was higher with barley vs. corn-based diets (Surber and Bowman 1998; Rotger et al. 2006). Khorasani et al. (2001) however observed no difference in the ammonia concentrations in rumens of cattle fed corn or barley.

Processing grain increases the rate of fermentation and therefore can decrease rumen pH (Marshall et al. 1992; Yang et al. 2000; Beauchemin et al. 2001). This is important because rumen pH has the potential to alter rumen ammonia concentration. When ammonia is in its non-ionized form (NH_3) in the rumen, transfer across the rumen wall occurs quite rapidly, via diffusion (Rémond et al. 1996). Transfee of ammonia in the ionized form (NH_4^+) across the rumen wall occurs more slowly as it is not lipid-soluble so does not diffuse across the lipid layers of the cell membrane easily (Rémond et al. 1996). The pKa of ammonia is 9 (Leng and Nolan 1984), making it a weak base.

When pH decreases below this, ammonia is more likely to be in the NH_4^+ state. Since this is much higher than the pH of the rumen, most ammonia is present as NH_4^+. In fact, at pH 7 it has been demonstrated that 98.7% of ammonia is in this form and at pH 6, 99.9% of ammonia is present as NH_4^+ (Rémond et al. 1996). The decreased rate of movement across the rumen wall of NH_4^+ when pH is low allows it to accumulate in the rumen.

Rumen proteolytic enzymes perform best when rumen pH ranges from 5.5 to 7.0, but at the lower end of the spectrum protein degradation begins to show signs of depression (Kopecny and Wallace 1982). While this could mean that rumen ammonia will not accumulate when pH is decreased, decreased rumen pH also decreases rumen protozoal numbers, and decreased protein degradation means concentrations of peptides and amino acids are reduced, decreasing microbial protein synthesis (Bach et al. 2005). Even if microbial protein synthesis is low, if rumen protein degradation is occurring at a faster rate than rumen microbes are utilizing the nitrogen, ammonia can accumulate. Since processing often decreases rumen pH (Marshall et al. 1992; Yang et al. 2000; Beauchemin et al. 2001) it can be inferred that increased processing can also increase rumen ammonia concentration. Published results have been variable. Yang et al. (2000) and Koenig et al. (2003) found that feeding highly processed grain increased rumen ammonia levels. Beauchemin et al. (2001) and Bengochea et al. (2005) found no effect of processing on rumen ammonia levels, however Beauchemin et al. (2001) also observed no effect of processing on pH, and Bengochea et al. (2005) fed medium, as opposed to high, concentrate diets.

2.4.5 Rumen Lactate Concentration

Generally, lactate-utilizing microbes use up the majority of the lactate produced by lactate-producing microbes. However, lactate-utilizing microbes are sensitive to low pH conditions, while lactate-producing bacteria are not (Nocek 1997; Owens et al. 1998). If rumen pH is reduced lactate-producing microbes can proliferate, while lactate-utilizing microbes are depressed (Nocek 1997; Owens et al. 1998). This can result in an accumulation of lactate in the rumen. Under typical rumen conditions, rumen concentrations of lactate will not exceed 5 μM (Owens et al. 1998). Values such as 40 μM to 50 μM indicate severe, acute acidosis (Nocek 1997; Owens et al. 1998). However, rumen lactate levels are not usually elevated during subacute ruminal acidosis (Nocek 1997; Goad et al. 1998; Galyean and Rivera 2003).

2.5 Effects of Feeding Processed Cereal Grains on Carcass Quality

2.5.1 Fat Colour

Fat colour in beef is an important trait when it comes to consumer preference. Some markets prefer white fat while others prefer carcasses with fat with a more yellow tinge to it. Many countries which import beef from North America, such as those constituting the Asian market prefer beef with a hard white, as opposed to yellow fat (Yang et al. 1992; Yang et al. 1993; Knight and Death 1997; Boles et al. 2004). Beef with excessively yellow fat can be down-graded or condemned (Yang et al. 1992). White fat has also been linked to tenderness and improved palatability (Hodgson et al. 1992; Wulf et al. 1997). Due to the fact that downgrading can result in economic loss to the

producer, a great deal of work has gone into research targeting the control of fat deposition, including colour, in cattle.

While breed, species (*Bos taurus* vs. *Bos indicus*), herd of origin, and rate of gain impact fat colour, the major contributor appears to be diet (Brandt et al. 1992; Yang et al. 1992; Knight and Death 1997; Schnell et al. 1997; Yang et al. 2002; Boles et al. 2004). Pasture-fed beef cattle typically have a more yellow fat than grain-fed beef (Yang et al. 1993; Knight and Death 1997; Schnell et al. 1997; Yang et al. 2002). Corn-fed cattle have a more yellow fat than barley-fed cattle (Brandt et al. 1992; Boles et al. 2004). This is due to differences in levels of carotenoids in the feed because corn has high levels of carotenoids while barley has virtually none (Brandt et al. 1992; Knight and Death 1997; Schnell et al. 1997; Yang et al. 2002; Boles et al. 2004).

Carotenoids are the naturally-occurring pigments responsible for the bright yellows, oranges, and reds observed in fruits, vegetables, and flowers (Britton 1995; Knight and Death 1997), as well as the yellow colour in body fat of cattle (Yang et al. 1992; Yang et al. 1993; Knight and Death 1997; Yang et al. 2002). Carotenoids consist of a highly-conjugated polyene chain (Britton 1995). The electrons in the chain are excited by light in the visible wavelength range (400 to 500 nm), resulting in intense yellow, orange, and red colours (Britton 1995). The carotenoid family is very large. The 2 major carotenoids present in the adipose tissue of cattle are ß-carotene and lutein (Yang et al. 2002). Grasses grown on pasture are rich in these carotenoids (Yang et al. 1993; Knight and Death 1997; Schnell et al. 1997; Yang et al. 2002), but grains vary in their levels. Grains such as wheat and barley have negligible levels, while corn is relatively high in carotenoids (Brandt et al. 1992; Boles et al. 2004). Regardless of type of grain,

forages, particularly fresh pasture, are higher in carotenoids and therefore cattle finished on pasture have a more yellow fat (Yang et al. 1993; Knight and Death 1997; Schnell et al. 1997; Yang et al. 2002). When comparing the carcass fat of cattle finished on either barley or corn, cattle finished on corn will have a more yellow fat (Brandt et al. 1992; Boles et al. 2004).

2.5.2 Fatty Acid Profile

There are 3 common types of fatty acids: saturated fatty acids (SFA), mono-unsaturated fatty acids (MUFA), and poly-unsaturated fatty acids (PUFA) (Mir et al. 2003b). Saturated fatty acids have no double bonds, MUFAs have one double bond, and PUFAs have more than one double bond. Regarding human health, it is more desirable to consume PUFA as opposed to SFA (Mir et al. 2003b).

The fatty acid present in the highest proportion in beef fat is C18:1, or oleic acid, followed by C16:0 (palmitic acid) and C18:0 (stearic acid) (French et al. 2000; Griswold et al. 2003; Mir et al. 2003a; Mir et al. 2003b). Oleic acid is beneficial as it has been reported to have hypocholesterolemic properties (Bonanome and Grundy 1988). Palmitic and stearic acid, however, are undesirable as they have the opposite effect and are hypercholesterolemic (Mir et al. 2003b). The fatty acids, C18:2 and C18:3 (linoleic and linolenic acid, respectively), are essential fatty acids that are also present in beef fat (Mir et al. 2003a; Mir et al. 2003b). While these fatty acids are more vulnerable to lipid oxidation when compared to MUFA, and therefore may result in a cut of meat having shorter shelf life (Mir et al. 2003a), they are actually desirable fatty acids because of the health benefits they may provide (Mir et al. 2003b). Conjugated linoleic acid (CLA) is

an isomer of linoleic acid, and has antioxidative properties (Mir et al. 2003a). Eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) are both elongated products of linolenic acid and play a role in human health including preventing some chronic inflammatory diseases and are important in the development of brain and visual tissues during fetal growth and throughout life (Belluzzi 2002; Wainwright 2002; Mir et al. 2003b). While not the most efficient route of production, humans can produce EPA and DHA from dietary α-linolenic acid (Whitney and Rolfes 1996).

2.5.2.1 Biohydrogenation

When cattle ingest feed, extracellular lipases produced by a select group of bacteria hydrolyze the triacylglycerols, phospholipids and galactodyl lipids contained in the feed (Demeyer and Doreau 1999). This hydrolysis is rapid, so even when high levels of dietary fat are fed, the main lipid fraction in rumen and duodenal lipids is comprised of free fatty acids (Demeyer and Doreau 1999). Low rumen pH (below 6.0) and the feeding of ionophores can inhibit lipolysis (Demeyer and Doreau 1999). Free fatty acids are adsorbed onto feed particles in the rumen where they undergo hydrogenation and/or are incorporated into the lipid fraction of the bacteria associated with the particle (Demeyer and Doreau 1999). Two fatty acids commonly hydrogenated by bacteria are linoleic and linolenic acid.

2.5.2.2 Methods to Alter the Fatty Acid Profile of Cattle

A great deal of research has gone into methods of changing the fatty acid profile of cattle, particularly with respect to increasing the desirable PUFAs such as CLA, and

decreasing the SFA. Several factors affect biohydrogenation, including inhibition by low pH, ionophores, and the accumulation of intermediate products of biohydrogenation such as *trans*-18:1 and CLA (Demeyer and Doreau 1999). This explains why cattle fed high concentrate diets and/or ionophores such as monensin often have body fat with a higher degree of unsaturation (Demeyer and Doreau 1999). Since CLA is an intermediate of biohydrogenation, adding it as a supplement to the diet in the hopes of increasing CLA content of the carcass fat can actually have the opposite effect (Griswold et al. 2003). Margaric acid (C17:0) is an odd-chain fatty acids found in beef (Mir et al. 2003a). Mir et al. (2003a) were able to increase the level of C17:0 in cattle fed diets with added vitamin E. As a result of the added vitamin E, the diet had a higher TDN and a greater extent of digestion when compared to the control diet. They hypothesized that the greater digestibility of the diet resulted in the increased level of C17:0.

2.6 Summary of Literature Review

In the feedlot, cattle are finished on high grain diets. Barley and corn are most commonly used for this purpose in western Canada, with canola meal often added as a protein source. Due to physical differences between barley and corn, ruminal fermentation rates differ (Ørskov 1986; Owens et al. 1998). Barley has a thick outer hull and pericarp which, if left intact, inhibits microbial attachment and therefore reduces fermentation (Yang et al. 2000; Koenig et al. 2003). If cracked, however, microbes can access the starchy endosperm and thus rate of fermentation increases to a rate more rapid than that of corn (Owens et al. 1998). The pericarp of corn can be damaged by mastication alone (Yang et al. 2000). The starch granules, however, are bound tightly to

the protein matrix, therefore fermentation rate is relatively slow (Owens et al. 1998; Yang et al. 2000).

Processing increases the digestibility of grain (Mathison 1996; Nocek 1997; Galyean and Rivera 2003). It has been shown to increase ADG and improve feed efficiency (Mathison 1996; Bradshaw et al. 1996) so it is beneficial to process grain before putting it in a feedlot ration. As the results of processing grain beyond dry rolling have been variable, many feedlots in western Canada choose dry rolling as their method of processing. Unfortunately, there are drawbacks to processing grain too extensively. Highly processed grain results in very rapid and complete digestion and can result in increased risk of metabolic disease due to increased VFA production and decreased pH (Owens et al. 1998). Along with this comes the risk of metabolic disorders such as SARA. Sub-acute ruminal acidosis can result in increased day-to-day variation in DMI, decreased daily DMI, and reduced ADG (Owens et al. 1998; Yang et al. 2000). During SARA pH is depressed, VFA concentration is elevated, osmolality often increases, and the depressed rumen pH may result in accumulation of rumen ammonia (Rémond et al. 1996; Nocek 1997; Krajcarski-Hunt et al. 2002). Evaluation of these rumen parameters can give insight into rumen health and function.

Ground grain is not commonly fed. Due to the small particle size, it has an extremely fast digestion rate and as such increases the potential for SARA, leading to depressed DMI, ADG, and feed efficiency (Nocek 1997). One promising aspect about ground grain, however, is that DMI was depressed by 5% but feed efficiency was only depressed by 1% suggesting that DMI would not have to be increased to the level of

rolled barley fed steers for performance to be equal (Mathison 1981 as cited in Mathison 1996).

Diet does not only affect the rumen physiology of cattle. Barley fed cattle produce carcasses with hard, white fat. This trait is desirable in many markets (Yang et al. 1993; Knight and Death 1997; Boles et al. 2004). The major determinant of fat colour and fatty acid profile is diet (Yang et al. 2002; Boles et al. 2004). With colour, the carotenoid content of the feed determines how white or yellow the fat will be, with cattle fed forage having the most yellow fat, and cattle fed barley having whiter fat than corn fed cattle (Yang et al. 2002; Boles et al. 2004). If a feed is to be exported to a market that values bright white fat, it should be demonstrated that the imported feed has beneficial effects on carcass quality. The fatty acid profile of the fat should also be comparable to that of cattle fed the feed that the new product will be replacing.

The hypothesis of this study is that barley, ground and pelleted with canola meal can be used effectively during the backgrounding and finishing of beef cattle. To address this hypothesis, two trials were undertaken. The objective of the feedlot trial was to compare the performance of steers fed ground barley pelleted with canola meal vs. rolled barley fed with canola meal at the same level it is present in the pellet, throughout backgrounding and finishing by evaluating parameters such as DMI, ADG, feed efficiency, and days on feed. The objective of the metabolism trial was to evaluate rumen health and function, as well as to explain any differences observed in the feedlot trial by measuring rumen pH, VFA concentration and profile, ammonia concentration, and osmolality, as well as feeding behaviour of steers fed barley and canola meal or corn and canola meal in either ground then pelleted or rolled form.

3.0 EFFECT OF FEEDING A BARLEY/CANOLA MEAL PELLET VS. ROLLED BARLEY ON PERFORMANCE AND CARCASS QUALITY OF FEEDLOT STEERS

3.1 Introduction

Barley is grown throughout western Canada. It is relatively high in protein and energy, and when fed to cattle in feedlot rations it results in desirable gains and feed efficiency. Other benefits of barley include the fact that it is not presently genetically modified and feeding it to cattle results in a hard, white carcass fat that is desirable to consumers (Brandt et al. 1992; Yang et al. 1992; Yang et al. 1993; Knight and Death 1997; Boles et al. 2004). For these reasons, there is opportunity to export feed barley grown in western Canada to Japan and other countries. Export markets such as Japan have unique requirements in that they import both energy and protein sources. Combining barley with a protein source such as canola meal would enhance the export potential to such markets because it would be a product that provides both energy and protein. Pelleting to increase bulk density would further increase its attractiveness by reducing shipping costs. In addition, to prove that this is a valuable product it must be demonstrated that cattle fed the product perform equal to, or better than, cattle fed rolled barley, the method typically used to process barley for use in feedlot rations.

While processing barley is necessary to maximize cattle performance (Ørskov 1986; Mathison 1996; Owens et al. 1997; Yang et al. 2000; Koenig et al. 2003), there are drawbacks to processing it too extensively. Overprocessing causes the grain to be very rapidly fermented, resulting in accumulation of VFA and a subsequent drop in rumen pH which can lead to health problems such as acidosis, rumenitis, laminitis, and liver abscesses (Ørskov 1986; Nocek 1996; Narayanan et al. 1997; Yang et al. 2000;

Beauchemin et al. 2001). These disorders can result in reduced DMI and poor performance (Nocek 1996; Owens et al. 1998; Krajcarksi-Hunt et al. 2002). Therefore, research is required to examine the effects of feeding pelleted barley on feedlot performance, particularly if it affects the incidence of SARA. The objectives of this trial were to compare the performance and carcass quality characteristics of steers fed pelleted vs. rolled barley, with each treatment containing canola meal.

3.2 Materials and Methods

3.2.1 Animals, Housing, and Experimental Design

Three hundred and fifty recently-weaned cross-bred steers (285 $\pm$ 22 kg) were housed at the University of Saskatchewan Beef Cattle Research Unit. The steers were vaccinated on arrival for clostridial diseases, infectious bovine rhinotracheitis (IBR), and parainfluenza 3 (PI_3), implanted with Ralgro™ (Schering Canada Inc., Pointe-Claire, PQ), and treated with Ivomec™ (MSD AgVet, Division of Merck Frosst Canada Inc., Kirkland, PQ). All cattle received long-acting oxytetracycline (Liquamycin LA-200; Pfizer Canada Animal Health Group) on arrival. Steers were weighed and randomly assigned to one of 12 pens. Each of the 12 pens was then randomly assigned to one of two treatments. The trial consisted of a 70 d backgrounding period and a finishing period with an endpoint of 12 mm of backfat as measured by ultrasound or 680 kg body weight, whichever came first (Appendix Table C.1).

3.2.2 Treatments and Diets

Diets fed during the backgrounding and finishing phases were barley grain-based and were typical of those fed in western Canada (Table 3.1). Dietary treatments consisted of feeding the barley grain in a rolled (RB) or ground then pelleted form (PB). Barley in the pelleted form included canola meal in the pellet. Prior to pelleting, the barley was ground using a hammer mill fitted with a 3.175mm screen. The pellet consisted of 85% ground barley and 15% canola meal (DM basis) during backgrounding, and 94% ground barley and 6% canola meal (DM basis) during finishing. Canola meal was added to the total mixed ration (TMR) of the RB-fed steers at a level equal to that in the PB treatment.

Steers were fed 3 different forage-based backgrounding diets, with the primary diet fed throughout this phase consisting of 23% barley silage, 28% brome grass hay, 3% barley straw, and 46% barley-based concentrate (DM basis). The diet was formulated to 1.55 and 0.95 Mcal kg^{-1} NE_m and NE_g, respectively. On day 42 of backgrounding adjustments were made to the diet to control gain: the forage content was increased from 54% to 58% (DM basis). This reduced NE_m and NE_g to 1.50 and 0.91 Mcal kg^{-1}, respectively.

During finishing, 6 intermediate diets were fed over a 24 d period to allow rumen microbes and papillae to adapt to the final finishing diet, which consisted of 7% barley silage and 93% barley-based concentrate (DM basis). Finishing diets were formulated to 1.94 and 1.29 Mcal kg^{-1} NE_m and NE_g, respectively.

Table 3.1. Average chemical composition and analysis of rations fed during the feedlot trial.

	Backgrounding		Finishing	
Item	Pelleted Barley	Rolled Barley	Pelleted Barley	Rolled Barley
Total mixed diet, % DM basis				
Barley silage	23	23	7	7
Brome grass hay	28	28	-	-
Barley straw	3	3	-	-
Barley grain, rolled	-	35	-	83
Canola meal	-	6	-	5
Ground barley and canola meal pellet[z]	41	-	88	-
Supplement	5	5	5	5
Supplement, % DM basis				
Barley grain	51.0	51.0	51.0	51.0
Tallow	3.4	3.4	3.4	3.4
Molasses	3.6	3.6	3.6	3.6
Limestone	8.8	8.8	8.8	8.8
Rumensin premix[y]	9.2	9.2	9.2	9.2
Trace mineral salt[x]	9.4	9.4	9.4	9.4
LS 106[w]	14.6	14.6	14.6	14.6
Chemical composition, DM basis				
Crude protein, %	13.37	13.37	13.72	13.72
Calcium, %	0.56	0.56	0.31	0.31
Phosphorous, %	0.31	0.31	0.36	0.36
Calculated energy content, DM basis[v]				
Digestible energy (DE), Mcal kg^{-1}[u]	2.44	2.44	2.89	2.89
Total digestible nutrients, %	67.49	67.49	80.08	80.08

[z] Ground barley:canola meal = 85:15 (DM basis) during backgrounding, 94:6 (DM basis) during finishing.

[y] Rumensin premix: 3% monensin sodium or 30 000 mg kg^{-1} monensin sodium.

[x] TM Salt: 95% salt, 12 000 ppm zinc, 10 000 ppm manganese, 4 000 ppm copper, 400 ppm iodine, 60 ppm cobalt, 30 ppm added selenium.

[w] LS 106 = 440 500 IU vitamin A, and 88 000 IU vitamin D_3 kg^{-1}.

[v] Calculated using NRC (1996) metabolizable energy values and equations for conversion to NE_M and NE_G.

[u] Digestible energy: 1 kg TDN = 4.4 Mcal DE (NRC 1996).

Throughout the backgrounding and finishing phases, diets were fed *ad libitum.* All barley used during the trial was obtained from a single commercial source. The brome grass hay, barley silage, and barley straw were obtained from the University of Saskatchewan farm. The hay and straw were processed through a Duratech Hay Buster (Model H1000) fitted with two 7.6 mm screens. Animals were fed twice daily at approximately 0830 and 1500.

3.2.3 Feed Sampling

Bunk feed samples were taken every 2 weeks. Samples were taken from the feedbunks immediately after feeding. Individual ingredients were also sampled. During finishing all bunks were cleaned on a bi-weekly basis and weight of orts recorded. Samples of this remaining feed were taken for determination of particle size.

3.2.4 Performance Data Collection

Throughout the trial, daily pen feed intake values were recorded. During backgrounding, steers were weighed every 4 weeks. Backfat thickness and *longisimuss dorsi* area were measured using ultrasound at receiving and at the end of backgrounding. During finishing steers were weighed every 2 weeks and backfat thickness and ribeye area were measured every 4 weeks as well as immediately before slaughter. Ultrasound procedures were based on those of Bergen et al. (1997) and were carried out using an Aloka 500 V realtime ultrasound machine and a 17 cm linear array transducer.

3.2.5 Slaughter

Steers were slaughtered at XL Beef in Moose Jaw, SK. Blue tag data was collected for each animal. This data included shrunk weight, hot carcass weight, dressing percent, backfat thickness, *l. dorsi* area, marbling score, and ruler yield. Forty steers were randomly selected (20 from each treatment group) and slaughtered at Plains Processing, Carmen MB. From these animals an 8-bone rib section was removed and stored at -20ºC. Subcutaneous (brisket) and body cavity (kidney) fat samples were collected from each carcass for fatty acid analysis. These samples were stored at -30ºC until further analysis.

3.2.6 Liver Abscess Score

At slaughter, livers were scored for abscesses. The abscess score ran from 0 to 3 and was based on the methods used by McKinnon et al. (1992). The scores were assigned based on the following criteria: 0 = no abscess; 1 = one small abscess; 2 = two to four small to medium abscesses; 3 = one or more large abscesses or greater than four small to medium abscesses.

3.2.7 Rib Dissection

The 8-bone rib section was thawed, weighed, then physically dissected into separable muscle, fat, and bone. The fat was further sub-divided into subcutaneous, intermuscular, and body cavity depots (McKinnon et al. 1993). A 5 cm^2 sample of subcutaneous fat was taken for color measurement. This sample was vacuum-packed and stored at -30ºC. A 2.5 cm-thick steak from the *l. dorsi* was also removed for

determination of fatty acid profile. It was vacuum-packaged and stored at -30ºC until analysis could be carried out.

Percent carcass bone, lean, and fat were determined according to the equations of McKinnon et al. (1993):

Carcass Lean % = 17.223 + (0.797 * % rib lean)

Carcass Fat % = 3.00 (0.76 * % rib fat)

Carcass Bone % = 100 – (carcass lean % + carcass fat %)

3.2.8 Fat Color Analysis

Colour was measured using a HunterLab MiniScan XE colour metre (Hunter Associates Laboratory Inc., Reston, Virginia) and evaluated using the Commission International de l'Eclairage (CIE) scale. Values measured consisted of L* (lightness), a* (red-green scale), and b* (yellow-blue scale). The L* scale runs from 0 to 100 with 0 indicating black and 100 indicating white. Both the a* and b* scales range from negative to positive with negative values representing green (a*) and blue (b*) and the positive values representing red (a*) and yellow (b*). The incandescent light was set to illuminant A while the angle of observation was set at 10 for all samples. The machine was standardized using coloured tiles provided by Hunter Associates Laboratory, Inc (Reston, Virginia). Samples were allowed to thaw at 4ºC overnight prior to analysis. While samples were still in their vacuum-pack bag, they were placed directly onto the colour metre and measured. The sample was then rotated 90º and the measurement repeated. If the values did not agree to within $\pm$ 0.7 units a third measurement was taken (H. Silcox, personal communication). The average of the 2 readings was reported.

3.2.9 Fatty Acid Analysis

3.2.9.1 Sample Preparation

Longisimuss dorsi samples collected during the rib dissections were thawed at 4ºC overnight and cut into 2.5 cm slices, then ground twice in a meat grinder fitted with a 32 mm plate. The samples were again vacuum packaged and stored at -30ºC until fat extraction took place.

3.2.9.2 Fat Extraction

Fat was extracted from the ground meat samples (15 g) using a procedure based on Bligh and Dyer (1959). Samples were comprised of sub-samples from several different areas of the ground sample. Adaptations to the procedure of Bligh and Dyer (1959) are detailed in Appendix A. The original procedure requires that the meat sample be homogenized with chloroform, methanol, and distilled water, and then filtered. At this point some additional steps were added. The flask that had contained the homogenate before filtering was rinsed twice with 5 mL of chloroform to recover any fat remaining in the flask. This chloroform was filtered with the rest of the homogenate. When the filtrate was transferred to separatory funnels, the flask containing the filtrate was rinsed with 5 mL of chloroform and added to the funnel. A few crystals of *tert*-butylhydroquinone (Sigma-Aldrich Inc.), an antioxidant, were added to each funnel to prevent oxidation. When separation was complete, the exact volume of the chloroform layer was recorded and the solution transferred to a round-bottomed flask. A 5 mL aliquot of the chloroform layer was added to each of two dried, labeled, and pre-weighed aluminum weighboats. These weighboats were then dried completely and re-weighed for

determination of fat content. The flask containing the remainder of the chloroform layer was placed under vacuum and heat to evaporate the chloroform. The fat was then stored at -20°C until methylation.

3.2.9.3 Determination of Intramuscular Fat Content

During fat extraction, one 5 mL aliquot of chloroform containing the lipid was pipetted into each of two pre-weighed aluminum weighboats. The fat content of the sample was determined using these aluminum weighboats. The samples were dried in a fumehood and transferred to a 100ºC oven for 1 h, then placed in a dessicator for 20 mins, following which they were again weighed. The weight of the fat in each tray was determined by subtracting the weight of the tray before the sample was added from the weight of the tray after the sample was added and dried down. The amount of fat in the 15 g sample was then determined using the following equations:

- $g\ chloroform\ g^{-1}\ sample = \frac{volume\ of\ chloroform}{weight\ of\ meat\ sample}$
- $g\ fat\ ml^{-1}\ of\ chloroform = \frac{(wt\ of\ fat\ in\ tray\ 1 + weight\ of\ fat\ in\ tray\ 2)/2}{5\ mL}$
- $g\ fat\ g^{-1}\ sample = \frac{mL\ chloroform\ g^{-1}\ sample}{g\ fat\ mL^{-1}\ chloroform}$

Amount of fat extracted was corrected using a 95.6% extraction efficiency factor. The value of this correction factor was determined by extracting a meat sample in triplicate following the procedure of Bligh and Dyer (1959). Average fat content for this sample was calculated and recorded. The filter paper used during the filtering process plus the meat sample residue were then extracted following the same procedure. Fat content was calculated, and the same method repeated on the filter paper and residue

from the second extraction. It was assumed that any fat remaining un-extracted after 3 extractions would be of a negligible amount. The proportion of fat extracted after a single extraction represented 95.6% of the fat extracted after 3 extractions.

For the current study, samples were run in triplicate, and values reported were an average of the 3 values. If the coefficient of variation between the 3 values was greater than 10, the outlying value was dropped and the coefficient of the 2 remaining values calculated. If the CV was less than 10, the average of the 2 remaining values was reported. If the CV was greater, the sample was re-extracted and fat content determined again.

3.2.9.4 Fatty Acid Methylation

Following fat extraction, fatty acids were methylated for analysis via gas chromatography (GC). The procedure used was based on the procedure of Keough and Kariel (1987) (Appendix B). After methylation, samples were filtered through a glass filter syringe into GC vials. The GC vials were flushed with nitrogen before being capped and wrapped in parafilm. Samples were stored at -20ºC until analysis on the GC.

3.2.9.5 Gas Chromatography

The methylated fatty acid samples were injected into an Agilent 6890 Series GC system (Agilent Technologies, Wilmington, DE) by an Agilent 7683 Series injector (Agilent Technologies, Wilmington, DE) fitted with a fused silica capillary column (SP 2560, Supelco; 100.0 m x 250 μm x 0.20 μm). The injector temperature was held at 240ºC. The initial column temperature was 140ºC (held for 5 min) and then programmed

to increase at a rate of 4 ºC min^{-1} to 240ºC (held for 10 min). The detection temperature was 250ºC. A standard curve was prepared to analyze the data, and all standards used to make to curve were purchased from Nu-Chek Prep, Inc. ((Elysian, MN).

3.2.10 Particle Size Analysis

During finishing samples of the refused feed were collected every 2 weeks and frozen at -20ºC. Thawed samples were divided into approximately 250 g portions. Each 250 g sample was separated, as is, using 3 U.S. Standard Sieve Series screens (The W.S. Tyler Company of Canada Ltd, St. Catharines, ON) with 3.36, 2.00, and 1.00 mm openings. After separating each sample, feed remaining on top of the top 3 screens was collected in a pre-weighed paper bag, and feed below the 1 mm screen was collected in a different pre-weighed paper bag. This process continued until the entire sample was separated. Bags were then weighed, dried thoroughly in a 55°C forced-air oven, and weighed again to determine DM content. The proportion of feed particles that fell through the 1.00 mm screen was reported as a percent of the entire feed sample (DM basis).

3.2.12 Statistical Analysis

All feedlot results were analyzed as a completely randomized design using pen as the experimental unit. The PROC MIXED procedure of the Statistical Analysis System Institute Inc. (SAS) version 9.1 (2003, Cary, NC, USA) was used. The Kenward Roger adjustment on denominator degrees of freedom was used. Repeated measures were used when analyzing daily DMI as well as daily variation in DMI. The GLIMMIX macro

provided by Statistical Analysis System Institute Inc. (SAS) (2003) technical support was utilized for a binomial error structure with logic transformation of data to analyze liver abscess and marbling data. All differences were considered significant at $P < 0.05$.

3.3 Results and Discussion

3.3.1 Backgrounding Phase

Backgrounding is a time when cattle are fed low-concentrate diets to control skeletal and muscle development and minimize fat accretion (Vaage et al. 1998; Block et al. 2001; Bengochea et al. 2005). Throughout the backgrounding phase in the current study, steers were fed a diet consisting primarily of 54% forage, 46% concentrate (DM basis) (Table 3.1). The backgrounding diet fed in this study is similar to backgrounding diets commonly fed in western Canada (Vaage et al. 1998; Block et al. 2001; Wang et al. 2003).

Dietary treatment had no effect ($P > 0.05$) on ADG during the backgrounding phase (Table 3.2). Gains were similar to gains reported by other workers who fed steers medium concentrate barley-based diets (Bengochea et al. 2005). Dry matter intake was reduced ($P<0.01$) for cattle fed the PB treatment compared to cattle fed the RB treatment (8.02 vs. 8.25 kg d^{-1}). Figure 3.1 shows the daily average DMI of both groups of steers over time. A lower ($P < 0.05$) DMI was observed for cattle on the PB vs. RB treatment on days 8 through 40 of the backgrounding phase.

The PB group had a higher standard deviation, and therefore showed more variation in DMI on day 1 and days 9 through 19, than steers fed RB (Figure 3.2). During backgrounding, the diet changed on day 2, 7, and 42. On day 7, level of

Table 3.2. Summary of the performance of steers fed either a pelleted or rolled barley-based diet during backgrounding and finishing.

	Treatment			
	Pelleted	Rolled	SEM[x]	*P* value
Start of test weight (kg)	323.4	323.3	0.24	0.92
End of test weight (kg)	643.7	642.6	2.81	0.79
Backgrounding				
Dry matter intake ($kg\ d^{-1}$)	8.02	8.25	0.05	0.01
Average daily gain (kg)	1.29	1.23	0.03	0.30
Feed:gain ($kg\ kg^{-1}$)	6.26	6.71	0.16	0.08
Finishing				
Dry matter intake ($kg\ d^{-1}$)	10.99	12.45	0.10	<0.01
Average daily gain (kg)	1.80	2.00	0.02	<0.01
Feed:gain ($kg\ kg^{-1}$)	6.03	6.21	0.04	0.01
Day 1 through Slaughter				
Dry matter intake ($kg\ d^{-1}$)	10.23	11.39	0.08	<0.01
Average daily gain (kg)	1.60	1.70	0.01	<0.01
Feed:gain ($kg\ kg^{-1}$)	6.27	6.64	0.05	<0.01
Days on test	196	186	2.24	0.01

[x] SEM = Pooled standard error of the mean

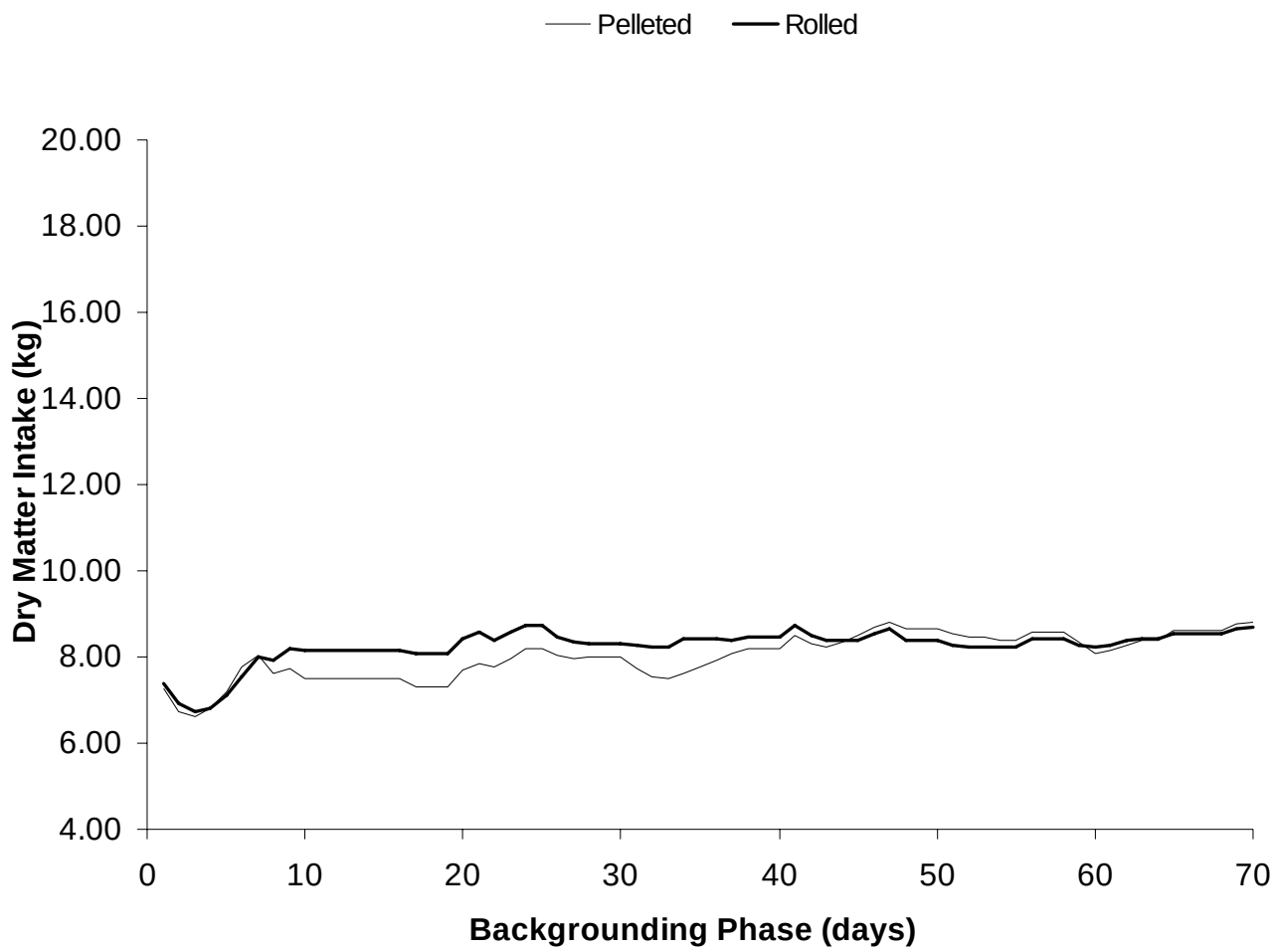

Figure 3. 1. Average daily DMI (kg) throughout backgrounding of steers fed a pelleted or rolled barley/canola meal diet. Steers fed RB ate more ($P < 0.05$) than steers fed PB on days 8 through 40.

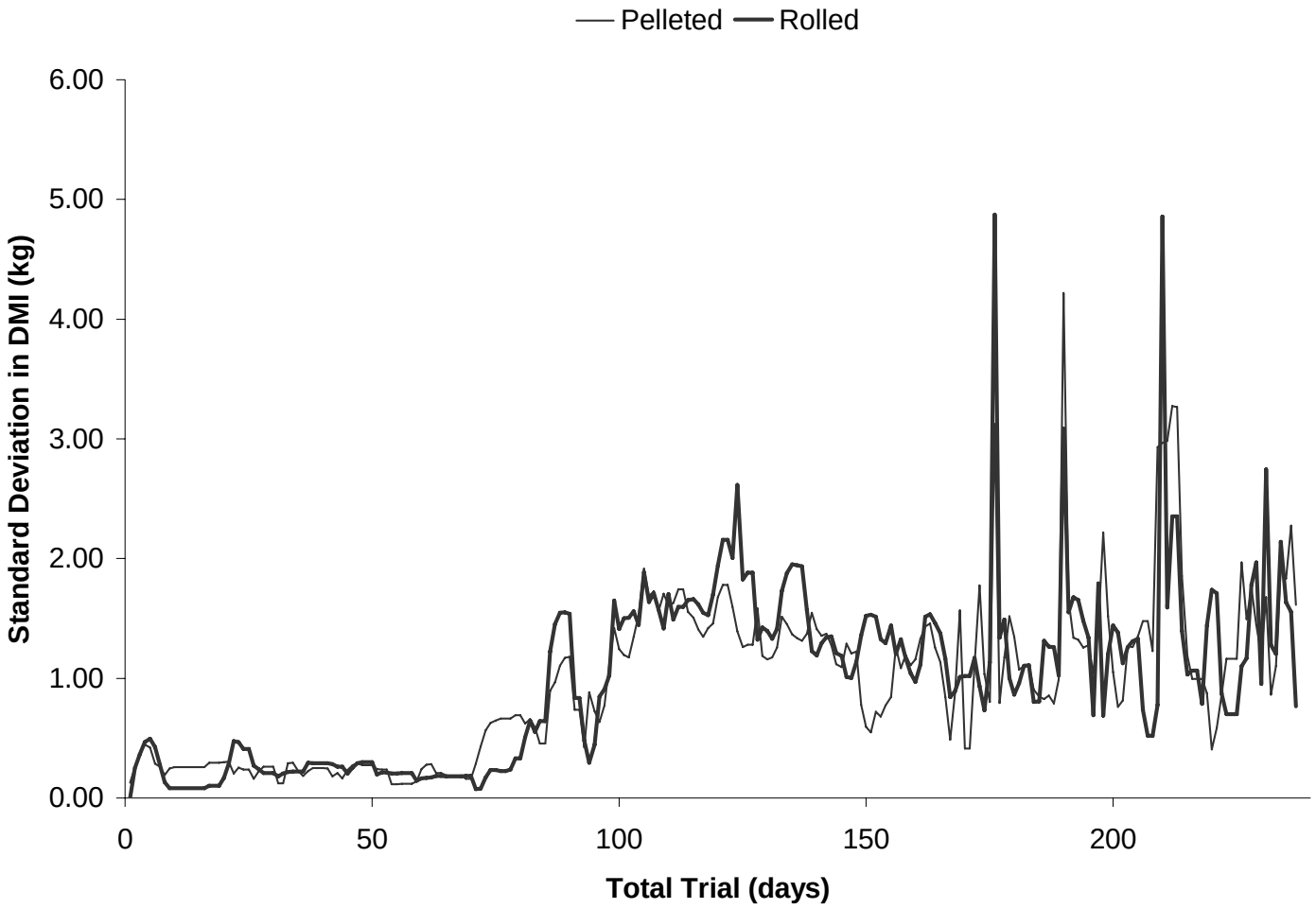

Figure 3. 2. Standard deviation (SD) in daily DMI (kg) throughout the total trial for steers fed a pelleted or rolled barley/canola meal diet. Steers fed PB had greater ($P < 0.05$) SD in DMI on day 1, 9-19, 71-78, 94, 207, and 209. Steers fed RB had greater ($P > 0.05$) SD in DMI on day 151.

concentrate increased from 34.5% of the total diet (DM basis) to 46%. This increase is relatively large and could account for the lower DMI in PB-fed steers beginning on day 8, as well as the increased variation in DMI on days 9 through 19. One of the consequences of feeding highly processed barley to cattle is the increased potential for SARA due to the fine particle size and thus rapid rate of starch fermentation (Ørskov 1986; Nocek 1996; Owens et al. 1998; Yang et al. 2000; Beauchemin et al. 2001). Sub-acute ruminal acidosis can lead to variation in day-to-day DMI and this can result in poor overall performance (Nocek 1996; Owens et al. 1998; Krajcarski-Hunt et al. 2002). Variation in DMI is often used as an index of SARA (Britton et al. 1991). The PB treatment showed more variation on 12 different days. Since all cattle were handled identically, being weighed and having ultrasound measurements on the same days, the only factor that differs is processing of the barley. It can therefore be assumed that feeding barley in a ground and pelleted form resulted in this increase in variation in DMI. The time when the onset of SARA is most likely to occur is during adaptation to a new diet (Galyean and Rivera 2003). Although both treatment groups were adapted to their respective diets in the same manner, the high rate of fermentation of the PB could make adaptation more difficult.

While cattle suffering from SARA do not typically appear sick (Owens et al. 1998; Galyean and Rivera 2003) the decreased pH of the rumen results in signs such as decreased performance, depressed DMI, and increased variation in daily DMI (Owens et al. 1998; Krajcarksi-Hunt et al. 2002). In this study PB-fed steers had depressed DMI and increased variation in DMI. It is likely that the reduced particle size resulted in the incidence of SARA in steers fed PB.

Although DMI was lower for the PB treatment relative to the RB treatment, ADG was similar ($P > 0.05$) between the treatment groups (Table 3.2). Animals fed PB were able to gain the same amount of weight as steers fed RB while using less feed. This was reflected in a tendency ($P = 0.08$) for PB steers to have lower, and thus improved, feed efficiencies (6.26 vs. 6.71) compared to RB steers. When PB represents a small portion of the ration, as in backgrounding, it is used very efficiently by cattle. The fact that ADG was not adversely affected by the PB treatment indicates that while the cattle may have been suffering from SARA, the extent of the disorder was not to the extent that growth was affected.

The goal of backgrounding programs is to promote muscle deposition while minimizing fat deposition (Vaage et al. 1998; Block et al. 2001; Bengochea et al. 2005). Table 3.3 shows that during the backgrounding phase of this trial *l. dorsi* area increased by 11.3 cm^2 for the PB fed steers and 10.2 cm^2 for the RB fed steers, while backfat only increased by 0.6 and 0.5 mm for PB and RB steers, respectively. No effects ($P > 0.05$) of treatment were observed. Other workers have noted similar rates of carcass lean and fat deposition in cattle fed barley-based diets during backgrounding (Block et al. 2001).

3.3.2 Finishing Phase

Typical western Canadian finishing diets are high in concentrate; this promotes energy efficient growth and fat deposition (Coleman et al. 1993; Vaage et al. 1998; Block et al. 2001). The finishing diet fed in the current trial (Table 3.1) is typical of finishing diets fed in western Canada (Beauchemin et al. 2001; Block et al. 2001; Beauchemin et al. 2003a; Wang et al. 2003; Bevans et al. 2005).

Table 3.3. Ultrasound backfat and *l. dorsi* measurements and gains during backgrounding, finishing and for the total trial in steers fed either pelleted or rolled barley-based diets.

	Treatment			
	Pelleted	Rolled	SEM[x]	*P* value
Backfat Thickness (mm)[z]				
Start of Test	2.3	2.3	0.13	1.00
End of Backgrounding	2.9	2.8	0.27	0.80
End of Test	11.1	11.7	0.18	0.07
Gain, Backgrounding	0.6	0.5	0.15	0.66
Gain, Finishing	8.3	8.9	0.17	0.03
Gain, Total Test	8.9	9.4	0.11	0.01
Longisimuss dorsi Area (cm^2)[z]				
Start of Test	56.1	57.4	0.89	0.31
End of Backgrounding	67.3	67.6	0.95	0.83
End of Test	102.2	100.3	1.12	0.26
Gain, Backgrounding	11.3	10.2	0.60	0.29
Gain, Finishing	34.9	32.7	1.06	0.18
Gain, Total Test	46.2	42.9	0.94	0.04

[x] SEM = Pooled standard error of the mean

[z] Ultrasound measurements

Steers fed PB had greater ($P < 0.05$) variation in DMI than those fed RB, as shown by the standard deviation of DMI, on days 71 through 78, 94, 198, 207, and 209 (Figure 3.2). Steers fed RB had greater ($P < 0.05$) variation than steers fed PB on day 151. Animal number in each pen began changing on day 85 of finishing due to animals being shipped for slaughter, and this may contribute to some of the increased variation after this day. Concentrate level of the finishing diets was increased on day 4, 6, 8, 11, 14, 20, and 24. These changes could explain the decreased DMI in the PB steers on days 16 through 22 and day 26 as these times are shortly after days when dietary changes occurred. These dietary changes may also explain the increased variation in DMI for PB steers on days 1 through 8 and 24.

One possible reason for the decreased DMI and increase in variation in DMI of PB-fed steers is the reduction in particle size and thus the potential of rapid fermentation of starch leading to SARA. In commercial feedlots, the degree of fines (i.e. particles passing through a 1 mm screen) is used to measure the potential for SARA and other bunk management problems (Mathison et al. 1997). In order to measure the degree of fine particles, orts were collected from the feed bunks every 2 weeks. Cattle fed PB had refused feed that had a greater proportion ($P < 0.05$) of particles that passed through a 1 mm screen (16.8 vs. 7.8%) than refused feed from the bunks of steers fed RB. Feeding ground barley has been shown to decrease DMI and increase the incidence of health problems such as depressed rumen pH, increased incidence of acidosis, rumenitis, and bloat (Cheng and Hironaka 1973; Hironaka et al. 1973; Hironaka et al. 1979; Zinn 1993; Mathison 1996). Steers fed ground barley have also been shown to have a reduction in ADG and poorer feed efficiency, and less carcass fat than steers fed rolled barley

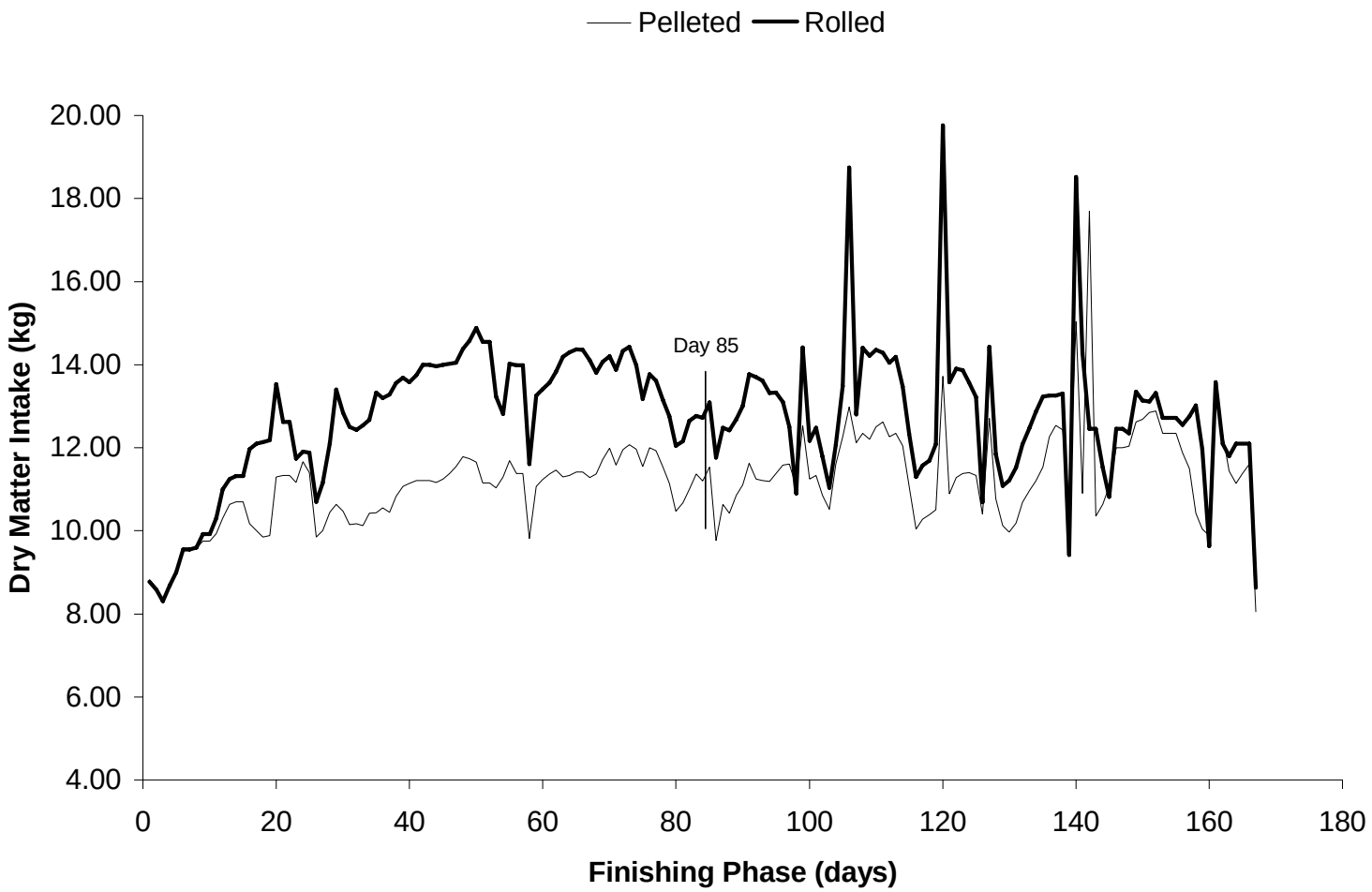

Figure 3. 3 Average daily DMI (kg) throughout finishing of steers fed a pelleted or rolled barley/canola meal diet. Steers fed RB had higher ($P < 0.05$) DMI than steers fed PB on days 16-22, 26-96, 99, 106, 108-114, 119-125, 127, 132-135, 140-143, and 158-159.

(Mathison 1981 as cited in Mathison 1996). The increased degree of fines in the PB vs. the RB is likely due to the fact that the barley was ground prior to pelleting and the pellets may have crumbled due to handling, transport, or moisture from weather or saliva.

Finishing ADG differed ($P < 0.05$) between the PB and RB treatments (Table 3.2). Cattle fed the PB treatment gained 1.80 kg d^{-1} while those fed the RB treatment gained 2.00 kg d^{-1}. Similar rates of gain of cattle fed barley-based rations have been reported by other workers (Block et al. 2001). Steers fed ground barley have been shown to have decreased ADG when compared to steers fed rolled barley (Mathison 1981 as cited in Mathison 1996), similar to what was observed in this study. The reduction in ADG was likely due to the decreased DMI of cattle fed PB. However, feed efficiency was improved ($P < 0.05$) for the PB treatment (6.03 vs. 6.21). Since ADG was lower for the PB treatment but feed efficiency was superior relative to the ADG and feed efficiency of steers fed RB, it can be inferred that the decrease in ADG was due to the depression in DMI. Minimizing the negative effect of feeding PB on DMI would be an important step to improving performance of cattle fed this product. Days on feed were greater ($P < 0.05$) for cattle fed PB. This is due to the fact that cattle were fed to a fixed end-point and the cattle fed the PB exhibited decreased ADG and thus took longer to get to this endpoint.

Owens et al. (1998) states that decreasing particle size of the feed increases the risk of acidosis. The high rate of starch fermentation with PB makes animals consuming this product more susceptible to SARA (Ørskov 1986; Nocek 1996; Owens et al. 1998; Yang et al. 2000; Beauchemin et al. 2001). Variation in DMI has been used as an index of SARA (Britton et al. 1991), and common signs of SARA, along with variation in DMI,

include decreased DMI and decreased performance (Nocek 1996; Owens et al. 1998; Krajcarski-Hunt et al. 2002). In the current study, cattle fed the PB treatment displayed increased variation in DMI, decreased DMI on a number of days, as well as an overall depression in average DMI. Feed efficiency was improved for PB, but intake was depressed to the point that ADG was also lower. The increased variation and decreased DMI and performance, taken together with physical aspects of the PB product, such as the fine particle size and therefore high fermentability, point to SARA.

At the end of finishing, RB steers tended ($P = 0.07$) to have more backfat than PB steers (11.7 vs. 11.1 mm) (Table 3.3). The gain in backfat between end of backgrounding and slaughter was greater ($P < 0.05$) for the RB steers vs. PB steers (8.9 vs. 8.3 mm). Steers fed ground vs. rolled barley have been shown to have less fat (Mathison 1981 as cited by Mathison 1996). It is possible the PB fed steers may have had less backfat due to the decreased DMI caused by the increased processing of the grain. End of test *l. dorsi* measurements also did not differ ($P > 0.05$) between the 2 groups, at 102.2 and 100.3 cm^2 for cattle fed the PB and RB groups, respectively. Gain in *l. dorsi* area over the total trial were 34.9 and 32.7 cm^2 for cattle fed the PB and RB treatments, respectively, and these were not different ($P > 0.05$). These gains in both backfat and *l. dorsi* area are similar to gains observed by other workers feeding steers barley-based diets (Block et al. 2001). The goal of a finishing program is to promote fat deposition (Coleman et al. 1993). A greater degree of growth both in muscle and fat, occurred during the finishing period compared to the backgrounding period, as can be noted from the difference between gains during backgrounding and finishing in backfat and *l. dorsi* area.

3.3.3 Performance throughout Total Test

During both backgrounding and finishing, DMI was depressed for the PB group compared to the RB group. Average DMI for the total trial was also lower ($P < 0.05$) for the PB treatment than the RB treatment (10.2 vs. 11.4 kg) (Table 3.2). During finishing, this depression in DMI was such that ADG was lower for the PB treatment than the RB treatment which was also observed for the total trial. Pelleted barley-fed steers gained less ($P < 0.05$) (1.60 vs. 1.70 kg d^{-1}) than the RB-fed steers. During backgrounding, feed efficiency tended to be improved for the PB-fed steers over the RB-fed steers, and this difference became significant during finishing. Data from the total trial shows that feed efficiency remains improved ($P < 0.05$) for the PB group when compared to the RB group (6.27 vs. 6.64).

The overall depression in ADG is very important, as steers were slaughtered at common endpoints of 12 mm backfat (as measured by ultrasound) or 680 kg bodyweight. It took steers fed PB longer ($P < 0.05$) than steers fed RB to reach these endpoints, at an average of 10 more days on feed (Table 3.2). An increased number of days on feed has a very large economic impact in the feedlot due to yardage costs and the cost of feed for those extra days. This difference in days on feed is a result of both the decreased ADG and decreased gain in backfat observed in PB steers during finishing and throughout the total test.

3.3.4 Carcass Characteristics

3.3.4.1 Carcass Grade and Composition

Steers fed PB had carcasses similar to steers fed RB (Tables 3.4 and 3.5). Hot carcass weight and dressing percent were similar ($P > 0.05$) between the treatment groups. Although there were differences ($P < 0.05$) in ultrasound backfat and *l. dorsi* area gain throughout the trial, there were no differences ($P > 0.05$) in backfat thickness or *l. dorsi* area between the treatments at the end of the test (Table 3.3). Carcass composition did not differ ($P < 0.05$) between treatments (Tables 3.4 and 3.5). These results are not surprising as cattle were slaughtered at a known endpoints of backfat thickness and body weaight. This also helps explain why dressing percent, lean meat yield, and marbling score did not differ ($P > 0.05$) between the treatments. There were minor differences in fat distribution between the treatments, however no negative effects of highly processed barley were observed. Carcass traits for both groups reflect what is typically observed in cattle fed in western Canada (Mir et al. 2003a).

The RB steers had greater ($P < 0.05$) proportion of intermuscular fat compared to PB steers (60.0 vs. 57.4%) while PB steers tended ($P = 0.06$) to have a greater proportion of subcutaneous fat than RB steers (30.8 vs. 28.4%). Results for both carcass composition and fat distribution are similar to results from other workers who fed steers barley-based diets (Block et al. 2001).

Liver abscesses are of economic concern to the Canadian feedlot industry. Liver abscesses can result in economic losses due to liver condemnation and decrease in production and feed efficiency (Brink et al. 1990; Nagaraja and Chengappa 1998; Smith

Table 3.4. Carcass characteristics and composition, fat distribution, and fat colour of steers fed either pelleted or rolled barley-based diets.

	Treatment			
	Pelleted	Rolled	SEM [x]	*P* value
Hot Carcass Weight, kg	372.3	368.7	2.44	0.32
Dressing %	59.6	59.3	0.21	0.33
Lean Meat Yield, %	60.8	60.1	0.22	0.06
Carcass Composition, %				
Lean	57.7	57.5	0.54	0.72
Fat	25.2	25.3	0.57	0.82
Bone	17.1	17.2	0.25	0.79
Fat Distribution, %				
Subcutaneous	30.8	28.4	0.88	0.06
Intermuscular	57.4	60.0	0.79	0.03
Body Cavity	11.9	11.7	0.45	0.74
Fat Colour [z]				
L*	76.0	77.5	1.49	0.32
a*	7.2	7.8	0.88	0.53
b*	14.2	14.4	0.59	0.75

[x] SEM = Pooled standard error of the mean.
[z] L* = lightness scale, 0-100; a* = red green scale, positive to negative; b* = yellow blue scale, positive to negative.

Table 3.5. Marbling scores observed in steers fed either pelleted or rolled barley-based diets.

	Treatment			
Marbling Score[z]	Pelleted	Rolled	SEM [x]	*P* value
Percentage with Score 5	0.6	1.0	0.8	0.71
Percentage with Score 6	0.6	0.0	0.0	1.00
Percentage with Score 7	29.1	31.6	2.7	0.52
Percentage with Score 8	67.9	67.3	3.0	0.90
Percentage with Score 9	1.8	0.0	0.5	1.00

[x] SEM = Pooled standard error of the mean.
[z] Marbling score, 1 = very abundant and 10 = devoid

1998; Checkley et al. 2005). The presence of liver abscesses in cattle has been shown to lead to depressed feed intake, weight gain, feed efficiency, and carcass dressing percentage (Brown et al. 1973; Brink et al. 1990; Nagaraja and Chengappa 1998). Brink et al. (1990) reported ADG to be decreased by as much as 11% and feed efficiency reduced by 9.7% in cattle with severely abscessed livers. In the current study, livers were scored for presence and severity of abscesses to indicate the degree to which SARA may have been present in the trial. Liver abscess scores were not different ($P > 0.05$) between cattle fed PB vs. RB (Table 3.6). This is surprising given the fact that diet is a major influencing factor regarding incidence of liver abscesses (Nagaraja and Chengappa 1998; Checkley et al. 2005), with more rapidly fermentable diets typically resulting in a higher incidence of abscesses due to greater fluctuations in rumen pH (Stock et al. 1990). It has also been reported that processing grain increases the incidence of abscesses (Nagaraja and Chengappa 1998). The PB diet was more highly processed and assumed to be more rapidly fermentable, however incidence and severity of liver abscesses was not different from that in the RB group. This could be due to the fact that both treatment groups received tylosin in the diet. Antibiotics in the feed have been proven to reduce the incidence of liver abscesses (Brown et al. 1975; Nagaraja and Chengappa 1998), with Galyean and Rivera (2003) reporting that tylosin is the most effective. The lack of grain processing effect on liver abscesses can also be due to good bunk management. Both groups of cattle were fed twice daily. This ensures all animals have room at the bunk, and therefore should also prevent over-eating, which can lead to metabolic disorders such as acidosis and liver abscesses. The incidence of liver abscesses in the current study was

Table 3.6. Liver abscesses observed in steers fed either pelleted or rolled barley-based diets.

	Treatment			
Liver Abscesses	Pelleted	Rolled	SEM[x]	*P* value
Percentage with Score 0[z]	79.8	91.4	4.4	0.13
Percentage with Score 1[z]	6.4	3.4	2.3	0.44
Percentage with Score 2[z]	5.3	1.7	2.3	0.36
Percentage with Score 3[z]	8.5	3.4	2.7	0.27

[x] SEM = Pooled standard error of the mean.

[z] According to McKinnon et al. (1992) where 0 = no abscess; 1 = one small abscess; 2 = two to four small to medium abscesses; 3 = one or more large abscesses or greater than four small to medium abscesses.

16.8% which is well within the range reported by Brink et al. (1990), which was 12 to 32%.

3.3.4.2 Fat Color

Fat colour is important to consumers, with a hard white fat favoured in many countries, including Canada and Japan (Yang et al. 1992; Yang et al. 1993; Knight and Death 1997; Boles et al. 2004). No differences ($P > 0.05$) were observed when looking at either the L*, a*, or b* measurements (Table 3.4). Processing the barley to a greater extent had no effect on fat color. The scale of most interest is the b* scale which is the yellow-blue scale. A positive number indicates the sample is more yellow than blue therefore a lower number is more desirable. The b* results for the PB and RB treatment groups, respectively, are 14.2 and 14.4, therefore both groups have very little yellowness in the fat.

3.3.4.3 Intramuscular Fat Content and Fatty Acid Profile

Degree of barley processing had no effect ($P > 0.05$) on intramuscular fat content. *Longisimuss dorsi* samples from PB and RB fed steers had similar proportions of fat (4.1 vs. 4.0%) (Table 3.7). International consumers, particularly those in Japan like beef with relatively high levels of marbling. If the PB negatively influenced intramuscular fat content, it may not be suitable for export to these international markets. This lack of effect on intramuscular fat content is not surprising as, stated previously, the animals in this study were slaughtered at similar endpoints. They also did not differ in lean meat yield or dressing percentage and had a similar amount of total carcass fat. The amount of

Table 3.7. Fatty acid profile, expressed as fatty acids/100 mg fatty acid, and fat content of steers fed either pelleted or rolled barley-based diets.

	Treatment			
Fatty acids, mg/100 mg fatty acid	Pelleted	Rolled	SEM [x]	*P* value
C14:0	3.29	3.35	0.15	0.77
C14:1	0.62	0.66	0.05	0.52
C16:0	30.08	29.56	0.50	0.47
C16:1	3.94	4.45	0.22	0.10
C17:0	1.66	1.33	0.06	<0.01
C18:0	14.62	14.74	0.31	0.80
C18:1	41.58	42.71	0.49	0.11
C18:2	3.08	2.28	0.48	0.25
C18:3	0.55	0.38	0.02	<0.01
C20:4	1.11	0.90	0.07	0.04
Total PUFA	4.74	3.56	0.47	0.08
Total MUFA	46.13	47.82	0.46	0.01
Total SFA	49.65	48.98	0.66	0.47
PUFA:SFA	0.10	0.07	0.01	0.10
Fat Content of *l. dorsi* (%)	4.11	4.02	0.23	0.78

[x] SEM = Pooled standard error of the mean.

l. dorsi intramuscular fat reported in the current study agrees with values reported by other workers who fed steers high grain finishing rations (Mandell et al. 1998).

In addition to the amount of intramuscular fat, the nature of the fatty acid profile of the carcass fat is important to both domestic and international consumers. Three classifications of fatty acids are the most common: saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) (Mir et al. 2003b). From a human health standpoint, it is desirable to decrease the intake of SFA and increase the intake of PUFA (Mir et al. 2003b). In ruminant fat, the most common fatty acid is oleic acid (C18:1) (French et al. 2000; Griswold et al. 2003; Mir et al. 2003a; Mir et al. 2003b). This was the case in the current study with both groups of cattle (Table 3.8). Oleic acid is known to have hypocholesterolemic properties (Bonanome and Grundy 1988). Levels of oleic acid did not differ ($P > 0.05$) between fat from steers fed PB vs. those fed RB. In the current study and in other published results (French et al. 2000; Griswold et al. 2003; Mir et al. 2003a; Mir et al. 2003b) the fatty acids present in the second and third highest concentrations are palmitic (C16:0) and stearic (C18:0) acids. These saturated fatty acids are hypercholesterolemic (Mir et al. 2003b) and therefore undesirable. Processing of barley had no effect ($P > 0.05$) on levels of C16:0 or C18:0 in beef. Processing did however, have an effect ($P < 0.05$) on margaric acid (C17:0) concentration. The PB group had a higher concentration ($P < 0.05$) of C17:0 than did the RB group. A study by Mir et al. (2003a) reported higher levels of C17:0 in beef fat increase when the cattle were fed diets with added vitamin E. The authors attributed this result to higher digestible nutrients and greater extent of digestion in cattle fed vitamin E. In the current study the PB ration had a greater proportion of fine particles

and was assumed to be more rapidly and thoroughly digested than the RB ration. The greater extent of digestion could therefore be the reason for the increased C17:0 in PB-fed steers.

There were also effects of diet on palmitoleic acid (C16:1) and arachidonic (C20:4) levels in the fat with PB-fed cattle tending to exhibit less ($P < 0.1$) C16:1 and having more ($P < 0.05$) 20:4 than RB-fed cattle. Arachidonic acid is an omega-6 fatty acid produced from linoleic acid that is essential for most mammals (Adisa and Odutaga 1999). These changes reflect relatively small changes in the fatty acid profile of carcass fat.

Linoleic (C18:2) and linolenic (C18:3) acids are both essential fatty acids (Adisa and Odutuga 1999). There are both advantages and drawbacks to having increased levels of these fatty acids in carcass fat. When compared to MUFA, they are more vulnerable to lipid oxidation which can result in a reduction in beef shelf life and meat quality (Mir et al. 2003a). These negative qualities are often ignored, however, because they are counteracted by the human health benefits they provide and because of conjugated linoleic acid's (CLA, a family of isomers of C18:2) antioxidative properties (Mir et al. 2003a; Mir et al. 2003b). While both the PB- and RB-fed groups exhibited similar levels of C18:2, the PB-fed group had more ($P < 0.05$) C18:3. There are 2 elongated products of C18:3, eicosapentaenoic acid (EPA, C20:5 n-3) and docosahexaenoic acid (DHA, C22:6 n-3), that play important roles in human health (Mir et al. 2003b) such as preventing certain chronic inflammatory diseases (Belluzzi 2002) and aiding in the development and maintenance of both brain and visual tissues in the fetus and throughout life (Wainwright 2002). While the process is not very efficient, humans can produce

EPA and DHA from C18:3 (Whitney and Rolfes 1996) so it is beneficial to consume meat containing higher levels of C18:3 such as that produced by the PB-fed group.

From a human health standpoint, it would be beneficial to produce beef with a lower level of SFA and a higher level of PUFA (French et al. 2000; Mir et al. 2003a; Mir et al. 2003b). While processing barley to a higher degree than rolling did not reduce total SFA present in beef, it did tend to increase ($P < 0.1$) the PUFA:SFA ratio. The PUFA:SFA ratio of the PB group was 0.10, similar to the reported value of 0.102 observed by French et al. (2000). An increase in this ratio is important, as it represents a potential improvement with regards to human health (French et al. 2000).

3.5 Conclusions and Implications

Steers fed PB throughout backgrounding showed performance comparable to or better than steers fed RB, with similar gains resulting from less DMI, resulting in improved feed efficiency. Pelleted barley-fed steers, however, showed greater variation in DMI over a number of days, and this can be accounted for by the increasing amount of concentrate in the diet and rapid fermentation of the ground and pelleted grain. During finishing, PB-fed steers consumed less feed, but in this phase of feeding, in contrast to the backgrounding phase, ADG was also reduced. This lowered ADG meant that steers fed PB took an average of 10 more days on feed to reach 12 mm backfat or 625 kg bodyweight. Feed efficiency, however, remained improved for the PB-fed steers indicating that it is the decrease in DMI that is reducing ADG. The increased variation in DMI in PB fed steers over several days points to SARA as the reason for the decreased intake. The proportion of feed particles less than 1 mm was greater for orts collected from bunks of PB-fed steers, and this could also be another explanation for decreased intake.

Steers fed ground barley have been shown to have reduced DMI and ADG, less fat, and an increased incidence of health problems such as acidosis, rumenitis, and bloat, as well as reduced rumen pH (Cheng and Hironaka 1973; Hironaka et al. 1973; Hironaka et al. 1979; Zinn 1993; Mathison 1996; Beauchemin et al. 2001).

Carcasses from PB and RB-fed steers were similar in hot carcass weight, dressing percentage, lean meat yield, marbling, and liver abscess scores. The carcass composition of the treatment groups also did not differ. Pelleted barley fed steers, however, tended to have more subcutaneous fat and had significantly less intermuscular fat. Processing did not have an effect on fat colour, PB fed steers retained the bright white fat that is traditionally associated with barley-fed cattle. Intramuscular fat content of the *l. dorsi* did not differ between PB and RB fed steers. There were minor differences in fatty acid profile, with PB fed steers having more C17:0, C18:3, and a tendency towards a greater PUFA:SFA ratio. The RB fed steers had a greater proportion of C18:1 and total MUFA.

Barley which has been ground then pelleted has potential to be a valuable product for export. This is proven by the superior performance of steers fed PB during backgrounding relative to performance of steers fed RB. Other positive aspects of PB are the fact that feed efficiency remained improved throughout the trial with in steers fed PB vs. those fed RB, and also the carcasses produced by the two treatments only had minor differences. The decreased ADG in finishing appears to be a result of decreased DMI and therefore it is important to identify what is causing this reduction as well as the greater variability in DMI. The increased incidence of fines and the variation in DMI indicate decreased rumen pH resulting in a digestive disorder such as SARA. Further research should target rumen metabolism of steers fed highly processed barley-based rations.

4.0 EFFECT OF PELLETED GRAIN VS. ROLLED GRAIN ON RUMEN FERMENTATION AND EATING BEHAVIOUR IN BEEF STEERS

4.1 Introduction

Research has been conducted to discover how to feasibly export Canadian-grown feed barley as countries are interested in producing cattle with carcasses similar to those of cattle finished in Canada fed this Canadian-grown grain. To increase the digestibility of grain it must first be processed. Processing also increases the bulk density which decreases shipping costs. One proposed method of processing barley for export is to grind the barley, then pellet it with canola meal as a protein source. To test the hypothesis that this product can be used to background and finish cattle, a full-scale feedlot trial was conducted. During the backgrounding phase of the feedlot trial steers fed pelleted barley had reduced DMI, but ADG and feed efficiency were similar to cattle fed rolled barley. During finishing, steers consuming pelleted barley showed improved feed efficiency (6.03 vs. 6.21) but DMI was depressed to the point that ADG was lower (1.80 vs. 2.00 kg d^{-1}). When looking at performance throughout the entire feeding period, feed efficiency was superior for the steers fed pelleted barley (6.27 vs. 6.64) but both DMI and ADG were depressed. Also, variation in DMI was higher over a greater number of days for the steers fed pelleted barley. As a result of the decreased ADG it took an average of 10 more days on feed (196 vs. 186) for the steers fed pelleted barley to reach the slaughter criteria (12 mm backfat or 680 kg body weight).

It was suspected that the poor performance observed in the feedlot trial was due to SARA. Sub-acute ruminal acidosis is a metabolic disease defined as a state where the pH of the rumen drops below 5.6 for more than 3 hours (Krehbiel et al. 1995; Gozho et al. 2005), however if it goes below 5.1 for a period of time it is considered acute acidosis

(Nocek 1997). It can lead to variation in DMI which can result in an overall reduction in DMI, and also reduced performance (Owens et al. 1998; Krajcarski-Hunt et al. 2002; Galyean and Rivera 2003). Sub-acute ruminal acidosis leads to variation in DMI because of fluctuations in rumen pH. The rapid fermentation observed in cattle fed highly processed grain diets can lead to a decrease in rumen pH, and subsequently variation in DMI (Yang et al. 2000). Barley is very rapidly fermented in the rumen, while in contrast corn is more slowly fermented (McAllister et al. 1993; Foley et al. 2006; Rotger et al. 2006). It is therefore of interest to look at rumen fermentation in cattle fed ground and pelleted barley, using corn as a comparison. These results may be able to explain the differences in performance observed in the feedlot trial.

The objective of this study was to study the effect of feeding barley in a highly processed form on rumen fermentation characteristics. Pelleted and rolled corn were included as treatments to compare grains with differing rates of fermentation.

4.2 Materials and Methods

4.2.1 Animals, Housing, and Experimental Design

Four steers surgically fitted with 10 cm (ID) ruminal cannulae (Bar Diamond, Parma ID), were housed individually in the University of Saskatchewan metabolism unit. Pens were 13 m^2, outfitted with rubber floor mats and had individual waterers. Steers were cared for according to the guidelines of the Canadian Council on Animal Care (CCAC, 1993).

Each steer was randomly assigned to one of four treatments. The experiment was 2 x 2 factorial in a Latin Square design with the factors being grain type (barley, *Hordeum*

vulgare or corn, *Zea mays*) and degree of processing (rolled or ground using a hammer mill fitted with a 3.175 mm screen then pelleted with canola meal). Each 23 d period consisted of a 13 d adaptation period during which the animals were adapted to their experimental diets, a 7 d adjustment period during which the steers received the high-concentrate experimental diets (Table 4.1) and a 7 d period during which chewing behaviour was observed for one 24 h period beginning on day 19, and one 24 h period where rumen contents were collected every 2 h beginning on day 22.

4.2.2 Treatments, Diets, and Feeding

Steers were fed a finishing diet with either rolled barley, rolled corn, pelleted barley/canola meal, or pelleted corn/canola meal as the concentrate. Four intermediate diets were used to adapt the steers to the final high-concentrate finishing diet. Each intermediate diet was fed for 3 d. Diets had the same proportion of concentrate (as fed basis), and were formulated to the nutrient levels shown in Table 4.1. The proportion of concentrate was formulated on an as fed basis, and as such the concentrate level on a DM basis differ slightly between corn and barley (Table 4.1). Both diets were formulated to meet NRC (1996) requirements for protein and energy, and contained 33 mg kg^{-1} monensin sodium (Elanco Animal Health, Calgary, AB). Fresh feed was measured and mixed each day before feeding, and animals were fed twice daily at 0800 and 1600 and cattle were fed to a slick bunk. Each morning feedbunks were cleaned and the remaining feed weighed so intake could be recorded. Each feed ingredient was sampled throughout the trial for analysis. Barley and corn for the experiment were purchased from one commercial source.

Table 4.1. Average chemical composition and analysis of rations fed during the metabolism trial.

Item	Treatment			
	Pelleted Barley	Rolled Barley	Pelleted Corn	Rolled Corn
Total mixed diet, % DM basis				
Barley silage	8.95	8.95	9.36	9.36
Barley grain	-	80.20	-	-
Ground barley and canola meal pellet[z]	85.20	-	-	-
Corn grain	-	-	-	79.22
Ground corn and canola meal pellet[y]	-	-	84.46	-
Canola meal	-	5	-	5.24
Supplement	5.84	5.84	6.17	6.17
Supplement, % DM basis				
Barley Grain	39.42	39.42	41.94	41.94
Tallow	3.32	3.32	3.29	3.29
Molasses	3.57	3.57	3.54	3.54
Canola meal	9.62	9.62	-	-
Limestone	8.74	8.74	8.66	8.66
Rumensin premix[x]	9.25	9.25	9.16	9.16
Trace mineral salt[w]	9.29	9.29	9.20	9.20
LS 106[v]	14.60	14.60	14.46	14.46
Urea	2.17	2.17	9.75	9.75
Chemical composition, DM basis				
Dry matter, %	78.23	78.23	74.75	74.75
Crude protein, %	12.47	12.47	12.49	12.49
Digestible intake protein (% of CP)	8.00	8.00	6.28	6.28
Calcium	0.35	0.35	0.35	0.35
Phosphorous	0.36	0.36	0.33	0.33
Calculated energy content, DM basis[u]				
Digestible energy (DE), Mcal kg^{-1} [t]	3.5	3.5	3.7	3.7
Total digestible nutrients, %	78.66	78.66	84.83	84.83

[z] Ground barley:canola meal = 94:6 (DM basis)

[y] Ground corn:canola meal = 94:6 (DM basis)

[x] Rumensin premix: 3% monensin sodium or 30 000 mg kg^{-1} monensin sodium.

[w] TM Salt: 95% salt, 12 000 ppm zinc, 10 000 ppm manganese, 4 000 ppm copper, 400 ppm iodine, 60 ppm cobalt, 30 ppm added selenium.

[v] LS 106 = 440 500 IU vitamin A, and 88 000 IU vitamin D_3 kg^{-1}.

[u] Calculated using NRC (1996) metabolizable energy values and equations for conversion to NE_M and NE_G.

[t] Digestible energy: 1 kg TDN = 4.4 Mcal DE (NRC 1996).

4.2.3 Feeding Behaviour

Starting at 0800 on day 19 of each period the chewing behaviour (eating, ruminating, or neither) of each steer was monitored every 5 min for 24 h. It was assumed that the behaviour observed at the 5 min intervals lasted the entire time between observations. Total time spent chewing was calculated as total time spent eating plus total time spent ruminating. Results were reported as time (in minutes) spent chewing in a 24 h period. All methods were based on those of Beauchemin et al. (2001) and Maekawa et al. (2002a, 2002b).

4.2.4 Rumen Fluid Collection and Rumen pH and Osmolality Measurements

Beginning at 0800 on day 22, rumen contents were collected from each steer every 2 h for a 24 h period. Feeding was staggered such that at the 0800 and 1600 collection times, steers were fed immediately after samples were collected. Contents were sampled from 4 locations: the feed mat, reticulum, dorsal sac, and ventral sac. Samples collected from each location were strained through 4 layers of cheesecloth and a 50 mL sample of filtrate from each location was measured then the 4 samples were composited for each animal at each collection time. Measurements of pH were taken in duplicate with a Model 265A portable pH meter (Orion Research Inc., Beverly, MA) immediately after straining the rumen fluid. If the two readings did not agree to within $\pm$ 0.02 units, a third measurement was taken (Orion Research Inc., Beverly MA). Three 5 mL aliquots of filtrate were taken. One aliquot was preserved by adding 1 mL of 25% (wt/vol) metaphospohoric acid (HPO_3) for determination of VFA concentration. Another aliquot was preserved by adding 1 mL sulfuric acid (H_2SO_4) for determination of

ammonium nitrogen, while the third aliquot was not acidified and was used for determination of osmolality. All samples were stored at -20°C until analysis.

Rumen fluid osmolality was measured by centrifuging the non-acidified samples at 2000 rpm for 10 min using a Beckman Centrifuge (Model TJ-6; Palo Alto, CA). The sample was analyzed using a Vapro™ Vapor Pressure Osmometer (Model 5520; Wescor Inc., Logan, Utah). Each sample was analyzed in duplicate, and if the second reading was not $\pm$ 5 mOsm/L of the first reading, a third reading was taken and the average of the 2 readings was recorded (C. Coghlin and D. Hall, personal communication).

4.2.5 Rumen Volatile Fatty Acid Analysis

Acidified rumen fluid samples were thawed prior to VFA analysis. Rumen fluid was transferred to micro-centrifuge tubes and centrifuged at 14000 rpm for 15 min in a Microfuge® 18 Microcentrifuge (Beckman Coulter™, Palo Alto, CA). Supernatant was pipetted into 12 x 75 mm culture tubes and crotonic acid added as an internal standard to a final concentration of 1 mg mL^{-1}. The samples were then filtered using a syringe and 0.45 μm filter and transferred to 2 vials for analysis of each sample in duplicate. Acids identified and quantified included acetate, propionate, isobutyrate, butyrate, isovalerate, valerate, and caproic acid. Total VFA concentration was calculated by adding together the concentrations of all of these acids (Ghorbani et al. 2002; Beauchemin et al. 2003a).

Samples were injected into an Agilent 6890 Series GC System (Wilmington, DE) by an Agilent 7683 Series injector (Wilmington, DE) fitted with an Agilent Technologies High Performance GC Capillary Column (30.0 m x 320 μm x 0.25 μm, Wilmington, DE). The injector was held constant at 250ºC with an initial column temperature of

100ºC (held for 1 min) and then programmed to increase at a rate of 8ºC min^{-1} to 200ºC. The flame ionization detector temperature was 350ºC. A standard curve was prepared to analyze the data, and all standards used to make to curve were purchased from Nu-Chek Prep, Inc. ((Elysian, MN), and this standard curve was used to calculate the molar proportion of acetate, propionate, and butyrate of the total VFA.

4.2.6 Rumen Ammonia Concentration

Rumen fluid samples acidified with H_2SO_4 were thawed and allowed to reach room temperature. The sample was then transferred into a 25 mL beaker and the ammonia concentration measured using an ion selective meter (Orion 720A ISE Meter, Thermo Electron Corporation, Beverly, MA) and an ammonium ion-selective electrode (Orion 93-18 Ammonium Ion-Selective Electrode, Thermo Electron Corporation, Beverly, MA). Two readings were taken from each sample and the average recorded. If the results did not agree to within $\pm$ 3 units then a third measurement was taken and an average of the two values that most agree was reported (Thermo Electron Corporation, Beverly, MA).

4.2.7 Statistical Analysis

Rumen fermentation parameters (pH, VFA concentration and profile, osmolality, ammonia) were analyzed using the PROC MIXED repeated measures procedures of the Statistical Analysis System Institute Inc. (SAS) version 9.1 (2003, Cary, NC, USA). The Kenward Roger adjustment on denominator degrees of freedom was used. Eating behaviour was analyzed using the PROC MIXED procedure of SAS, again using

Kenward Roger adjustment on denominator degrees of freedom. Least square means were calculated, and all effects were declared significant at $P < 0.05$.

4.3 Results and Discussion

4.3.1 Diets

The chemical composition of diets are presented in Table 4.1. The aim was to formulate diets to have equal CP levels. Due to the different CP content of the corn and barley used, different supplements had to be formulated for the barley and corn diets. It was not possible to formulate the diets to have both CP and DIP contents similar between the barley and corn-based diets. Therefore the intent was to formulate to equal CP levels while still reaching minimum DIP levels. The barley supplement included canola meal and a low level of urea (2.2% DM basis), while the corn supplement used no canola meal and a higher level of urea (9.8% DM basis). Both diets were formulated to have 12.5% CP (DM basis) using values from NRC (1996). The barley diet had a calculated DIP of 8.0% (DM basis) while the corn diet had a calculated DIP of 6.3% (DM basis) (NRC 1996). Cooper et al. (2002) found that in steers fed dry rolled corn using alfalfa hay and cottonseed hulls as the forage, the DIP requirement was met at 6.3% (DM basis). In the present experiment, although the corn and barley diets differed in DIP content, both diets contained adequate levels of DIP to support microbial protein synthesis and fermentation (Cooper et al. 2002).

4.3.2 Rumen Fermentation

No grain type by processing interactions were detected for any of the rumen fermentation variables measured. As such, the main effects for grain type (barley vs. corn) and processing (pelleted vs. rolled) on rumen fermentation variables are discussed.

4.3.2.1 Rumen pH

No differences ($P > 0.05$) in average rumen pH values were found between grain types (Table 4.2). Barley is more fermentable in the rumen than corn (McCallister 1993; Foley 2006; Rotger 2006), and therefore it would be assumed that a lower rumen pH would result. However, this is not always the case as results from several trials support the results from the current study (Casper et al. 1999; Foley et al. 2006; Rotger et al. 2006). It is possible that differences were not observed due to concentrate level of the diet or degree of processing of the grain in these studies, as Casper et al. (1999) and Foley et al. (2006) fed dairy diets with lower proportions of grain, while Rotger et al. (2006) was using high concentrate beef diets, but the grain was ground. It is possible in the present trial that processing the corn increased its rumen fermentability to a rate close to that of barley.

There was, however, an effect of processing on mean daily rumen pH (Table 4.2). Overall, steers fed pelleted grain had a lower ($P < 0.05$) average daily rumen pH (5.7 vs. 6.1) than steers fed rolled grain. This is in agreement with the findings of Yang et al. (2000) that increased processing leads to decreased ruminal pH. Results from this study also agree with those from Marshall et al. (1992). They compared ground and rolled

Table 4.2. Effects of processing (pelleting or rolling the grain) or grain type (barley or corn) on daily mean ruminal fermentation variables.

	Processing				Grain Type			
Measurement	Pelleted	Rolled	SEM[x]	*P* value	Barley	Corn	SEM[x]	*P* value
Rumen pH	5.7	6.1	0.90	<0.01	5.8	5.9	0.1	0.69
Osmolality, mOsm	288.3	283.8	7.70	0.69	287.1	285.0	7.7	0.86
Ammonia mg dL^{-1}	12.3	9.4	1.10	0.09	10.5	11.2	1.1	0.68
Total VFA, mM[z]	103.7	90.7	9.00	0.33	99.8	94.6	9.0	0.69
Acetate, %	47.4	52.1	2.40	0.18	48.6	50.9	2.4	0.52
Propionate, %	40.6	31.5	2.50	0.04	35.0	37.1	2.5	0.58
Butyrate, %	7.8	11.8	3.00	0.36	11.9	7.8	3.0	0.36
Acetate:Propionate	1.2	1.9	0.20	0.05	1.6	1.4	0.2	0.58

[x] SEM = Pooled standard error of the mean

[z] Total VFA is sum of acetate, propionate, butyrate, isobutyrate, valerate, isovalerate, and caproic acid

grain diets and found that the steers fed ground concentrate had lower rumen pH measurements at certain times, and also greater declines in rumen pH. Sub-acute ruminal acidosis is a metabolic disease that can be identified by decreased rumen pH measurements (Krehbiel et al. 1995; Nocek et al. 1997; Krajcarski-Hunt et al. 2002; Galyean and Rivera 2003). While an animal suffering from SARA may show no overt symptoms (Nocek 1997; Owens et al. 1998), the disorder causes increased variation in DMI, decreased DMI, and poor performance (Nocek 1997; Owens et al. 1998; Krajcarski-Hunt et al. 2002; Galyean and Rivera 2003). Highly processed cereal grains such as barley, wheat, and corn are more rapidly degraded in the rumen and as a result rumen pH is likely to decrease.

Consuming high levels of highly fermentable carbohydrates puts cattle at a greater risk of SARA. The feedlot portion of this study showed that cattle fed ground and pelleted barley showed great variation in DMI, decreased DMI, and also took more days to finish than steers fed rolled barley. To more completely analyze the results of the rumen pH measurements in relation to what was observed in the feedlot trial, corn was removed from the statistical model and only pelleted and rolled barley were compared. Steers fed pelleted barley had a lower ($P < 0.05$) average daily rumen pH (5.60 vs. 6.10) than steers fed rolled barley. Sub-acute ruminal acidosis has been defined in several ways, but is commonly assumed to occur when rumen pH measures between 5.6 and 5.1 (Krehbiel et al. 1995; Nocek 1997). Using this benchmark it can be inferred that steers in the feedlot trial fed pelleted barley suffered from SARA and the results can be used to explain the increased variation in DMI and reduced performance observed in this group of steers.

Rumen pH fluctuates throughout the day in response to fermentation after each feeding. There was an overall time effect ($P < 0.05$) on rumen pH (Figure 4.1). Rumen pH measurements in the current study range from 5.1 to 6.9, well within the range of published values (5.02 to 6.82) (Pylot et al. 2000; Beauchemin et al. 2003a; Jaeger et al. 2006). Since total VFA load impacts rumen pH (Beauchemin et al. 2003a) it would be expected that the daily rumen pH pattern would be the inverse of the daily total ruminal VFA concentration. This was the case in the present experiment (Figure 4.1). At 0800 when pH was highest, rumen VFA concentration was lowest. When pH was lowest, VFA concentration was highest. In general, rumen pH dropped after feeding, then rose again until the next feeding. This pattern had been observed by others (Pylot et al. 2000; Koenig et al. 2003; Bevans et al. 2005; Szasz et al. 2005). High concentrate diets often cause great fluctuation in rumen pH throughout the day (Pylot et al. 2000; Koenig et al. 2003; Bevans et al. 2005; Szasz et al. 2005). Steers in this study showed typical fluctuation in rumen pH throughout the day as a result of high concentrate feeding, however processing the grain to a greater extent did not cause any greater fluctuation in rumen pH.

4.3.2.2 Rumen Volatile Fatty Acid Concentration and Profile

There was no effect of treatment ($P > 0.05$) on total ruminal VFA concentration (Table 4.2). It might be expected that the greater rate and extent of rumen degradability of barley starch observed by some workers (Owens et al. 1998; Foley et al. 2006; Rotger et al. 2006) would lead to a higher rumen VFA concentration than cattle fed corn based diets. While some research has shown a difference in rumen VFA concentration between

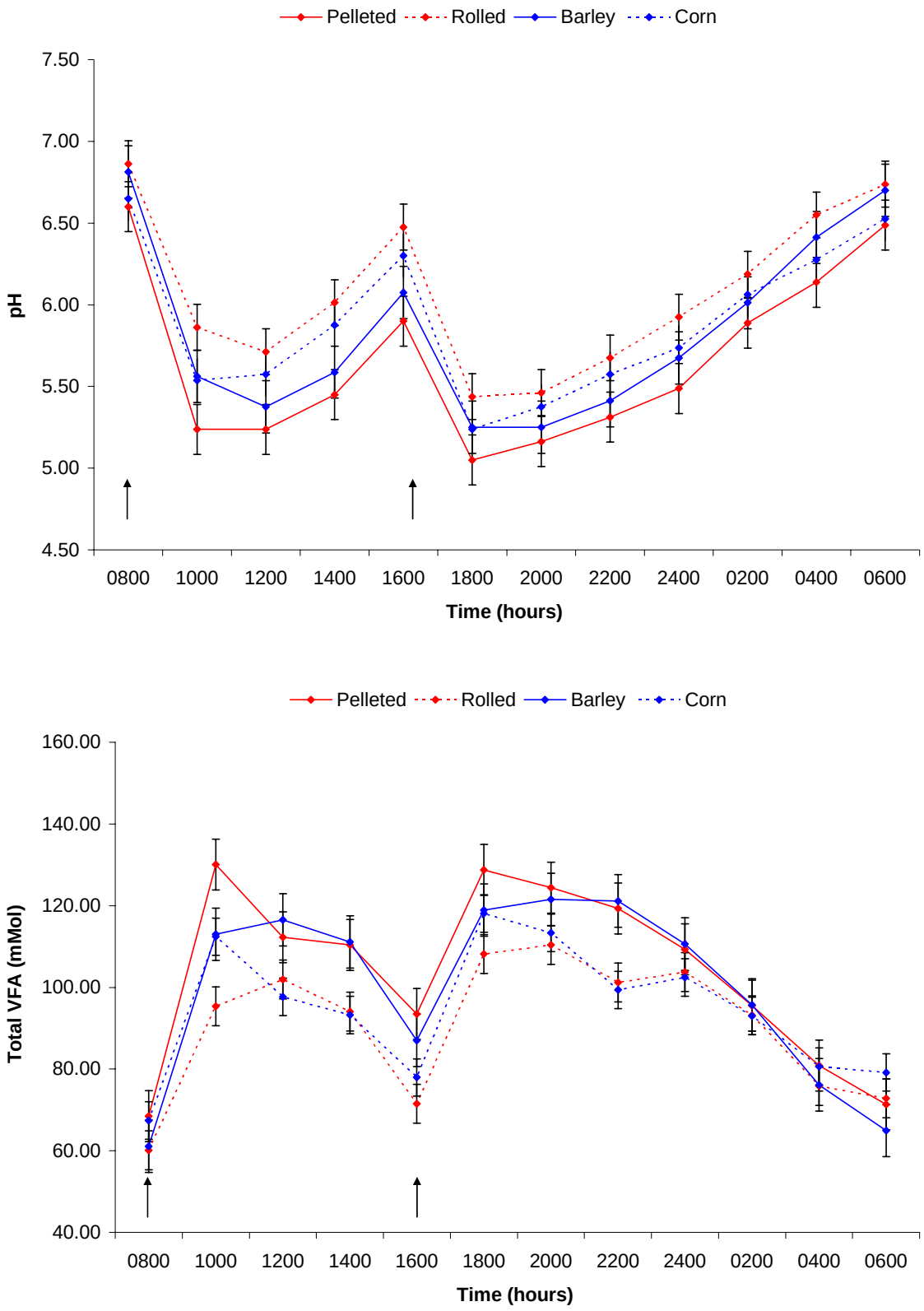

Figure 4. 1. Effects of processing (pelleted vs. rolled) and grain type (barley vs. corn) on rumen pH and total VFA concentration. Arrows represent feeding times.

barley and corn diets (Surber and Bowman 1998; Casper et al. 1999; Khorasani et al. 2001), this has not always been the case (Foley et al. 2006; Rotger et al. 2006).

While there was no effect of processing ($P > 0.05$) on total ruminal VFA concentration, steers fed pelleted grain exhibited higher ($P < 0.05$) ruminal VFA concentrations at the 1000 collection, the first collection following the first feeding of the day. This is in agreement with results from Marshall et al. (1992) who found that steers fed ground barley had higher VFA concentrations at 1 to 4 h post-feeding than steers fed rolled barley.

One of the primary objectives of this trial was to use the results to help explain performance differences in the feedlot trial. Since in that trial corn was not used as a treatment it was decided to again rerun the statistics without corn in the model. When this was done, steers fed pelleted barley had higher ($P < 0.05$) average daily rumen VFA concentrations (105.9 vs. 93.7 mM) than steers fed rolled barley (data not shown).

VFA load is negatively correlated with rumen pH (Beauchemin et al. 2003a). Results from the current study support this. Pelleted barley-fed steers had higher rumen VFA concentrations ($P < 0.05$) and lower rumen pH measurements ($P < 0.05$). Increased VFA concentration can indicate SARA, as an animal showing very high VFA concentrations often also has a lower rumen pH and is more likely to be suffering from the disorder (Krehbiel et al. 1995; Nocek et al. 1997; Owens et al. 1998; Galyean and Rivera 2003). The results of this trial point to rumen conditions for cattle fed pelleted barley indicative of SARA. This again can be used as an explanation for the poor feedlot performance of cattle fed PB in the feedlot trial.

There was a trend ($P = 0.06$) towards a processing by time interaction on total VFA concentration. There was also an effect of time ($P < 0.05$) on rumen VFA concentration (Figure 4.1). Average rumen VFA concentration was lowest at 0800, which is the collection after the longest fasting period in each 24 h period (Figure 4.1). The highest rumen VFA concentration was observed at 1000, which is the first collection after the morning feeding. Total ruminal VFA concentrations of the current study (60.1 to 130.1 mM) are near the range of 65 and 159 mM reported for cattle fed similar barley- or corn-based finishing rations (Pylot et al. 2000; Bevans et al. 2005; Rotger et al. 2006). As cattle consume feed, bacterial fermentation of carbohydrates in the rumen produces VFA (Rémond et al. 1996). These VFA are eventually absorbed across the rumen wall but immediately following a highly-degradable meal, VFA production can be greater than absorption such that VFA build up in the rumen (Owens et al. 1998). A cyclical pattern of VFA buildup and disappearance results, a pattern that is generally the inverse of the pattern followed by rumen pH. VFA concentration rises following a meal, and then falls steadily until the next feeding (Pylot et al. 2000; Beauchemin et al. 2003a; Bevans et al. 2005). Total rumen VFA concentration in the current study followed a similar pattern.

In the present experiment there was no effect ($P > 0.05$) of treatment or any interaction on molar proportion of acetate (Table 4.2). There was, however, an effect ($P < 0.05$) of time. The highest percent of acetate was observed at 0800, while the lowest proportion of acetate was recorded between 2000 and 2400 (Figure 4.2). Published values of ruminal acetate levels for cattle fed a high barley diet range from 48 to 56% (Pylot et al. 2000; Ghorbani et al. 2002; Beauchemin et al. 2003a; Bevans et al. 2005), while published ruminal acetate levels for cattle fed a corn-based finishing ration range

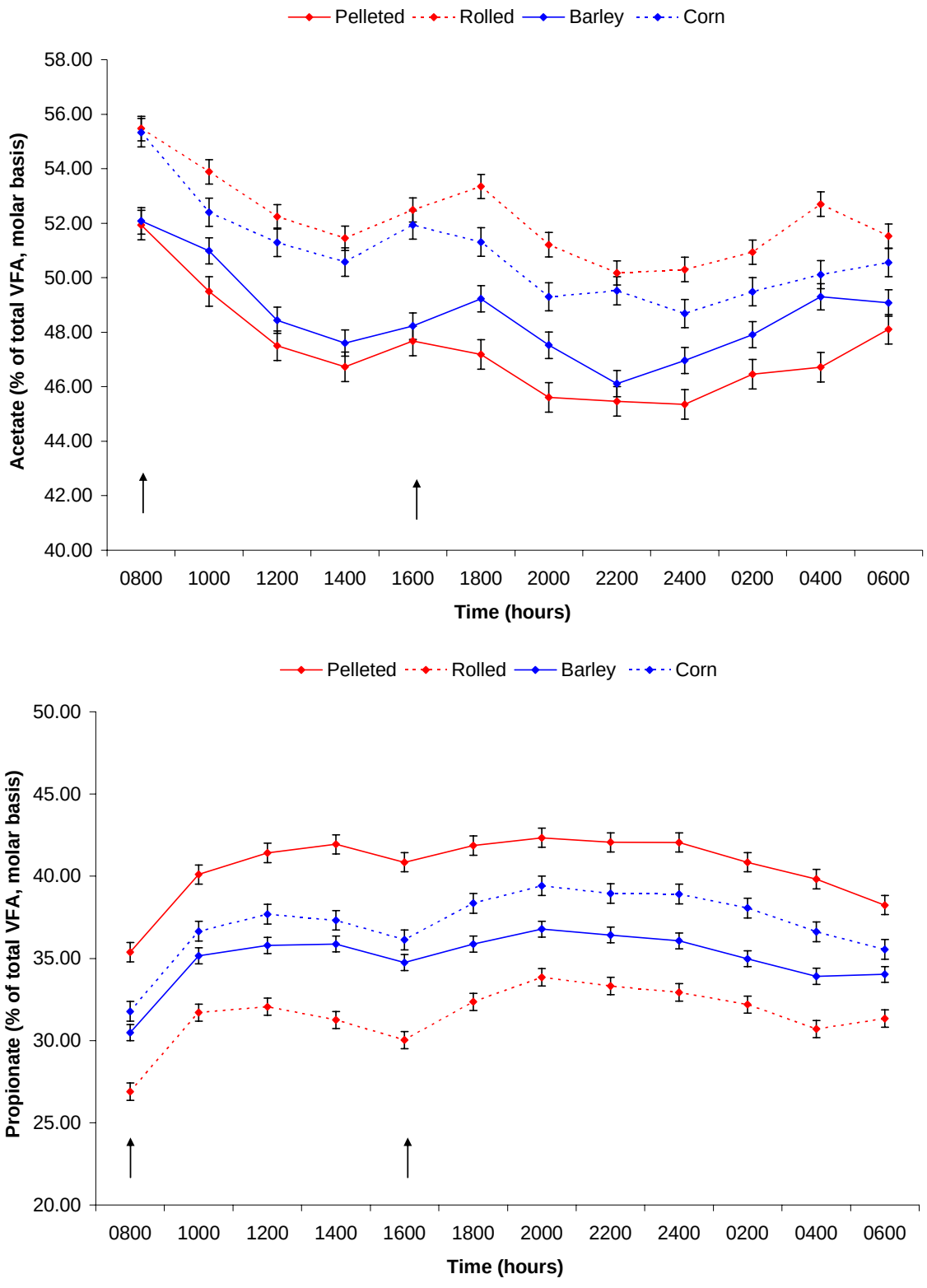

Figure 4. 2. Effects of processing (pelleted vs. rolled) and grain type (barley vs. corn) on ruminal molar proportion of acetate and propionate. Arrows represent feeding time.

from 41 to 52% (Szasz et al. 2005; Jaeger et al. 2006). These findings are very similar to results from the current study with acetate levels ranging from 46.1 to 52.1% and 48.7 to 55.3% for the barley and corn fed steers, respectively.

Steers fed pelleted grain had a higher ($P < 0.05$) average daily molar proportion of propionate (40.8 vs. 31.6%) than those fed rolled grain (Table 4.2). This difference was even greater when corn was removed from the model (41.2 vs. 28.8%; data not shown) for steers fed pelleted versus rolled barley. These results are in agreement with Yang et al. (2000) and Beauchemin et al. (2001) who showed that increased processing of grain leads to increased levels of propionate in the rumen. High levels of propionate in the rumen are desirable because propionate is a very energy efficient VFA (Van Houtert 1993). When propionate is produced, less transport of hydrogen is required, and less methane is being produced (Van Soest 1994). Higher levels of propionate also mean that more energy is going towards muscle accretion, as propionate is glucogenic, and the presence of it allows glucogenic to be used for protein synthesis as opposed to gluconeogenesis (Van Soest 1994; Beauchemin et al. 2003a) which is very important in beef animals. However, propionate has been shown to be hypophagic and thus can suppress appetite, decreasing DMI (Allen 2000; Oba and Allen 2003). This hypophagic effect is most likely due to chemoreceptors for propionate located in the liver (Allen 2000). The increased level of propionate measured in the pelleted barley fed steers could also explain the decreased DMI observed in the feedlot portion of this trial.

There was no effect ($P > 0.05$) of grain type on molar percentage of propionate (Table 4.2), and no interaction between grain type and processing level but there was an effect ($P < 0.05$) of time. The lowest levels were observed at 0800, immediately prior to

the first feeding of the day, while the highest levels were observed at 2000 (Figure 4.2). Propionate levels peaked after each feeding, and then fell until the next feeding. Similar patterns have been observed in other studies (Pylot et al. 2000; Beauchemin et al. 2003a). Published results of ruminal fluid propionate percentage measured in cattle fed barley and/or corn finishing diets range from 25 to 42% (Ghorbani et al. 2002; Beauchemin et al. 2003a; Szasz et al. 2005; Jaeger et al. 2006), similar to values in the present trial (26.9 to 42.3%).

Of the three main VFA, butyrate is typically present in the lowest amount (Van Houtert 1993; Rémond et al. 1996; Koenig et al. 2003). The range of molar percentage of butyrate in the present study was 6.3 to 13.7%, well within published values for similar high-grain diets (Table 4.2). Ruminants fed roughage-based diets typically have 5 to 10% of the total VFA comprised of butyrate (Van Houtert 1993) while cattle fed corn or barley-based finishing rations typically have molar percentages of butyrate ranging from 8.0 to 16.1% (Beauchemin et al. 2003a; Koenig et al. 2003; Szasz et al. 2005).

There was no effect ($P > 0.05$) of treatment (Table 4.2) or interaction of treatment with time, but there was an effect of time ($P < 0.05$) on proportion of butyrate. Butyrate levels dropped following the 0800 feeding, rose until the 1600 feeding when they dropped again, rising to the highest point at 2200 and slowly dropping again (Figure 4.3).

While there was no effect ($P > 0.05$) of grain type on acetate:propionate ratio, there was an effect ($P < 0.05$) of processing on this ratio (Table 4.2). Pelleting the grain resulted in an average daily ratio of 1.19 while rolling the grain resulted in a ratio of 1.86. The ratio of acetate to propionate is an important aspect to look at when evaluating a new feed. As proportion of acetate increases, efficiency of energy retention decreases with

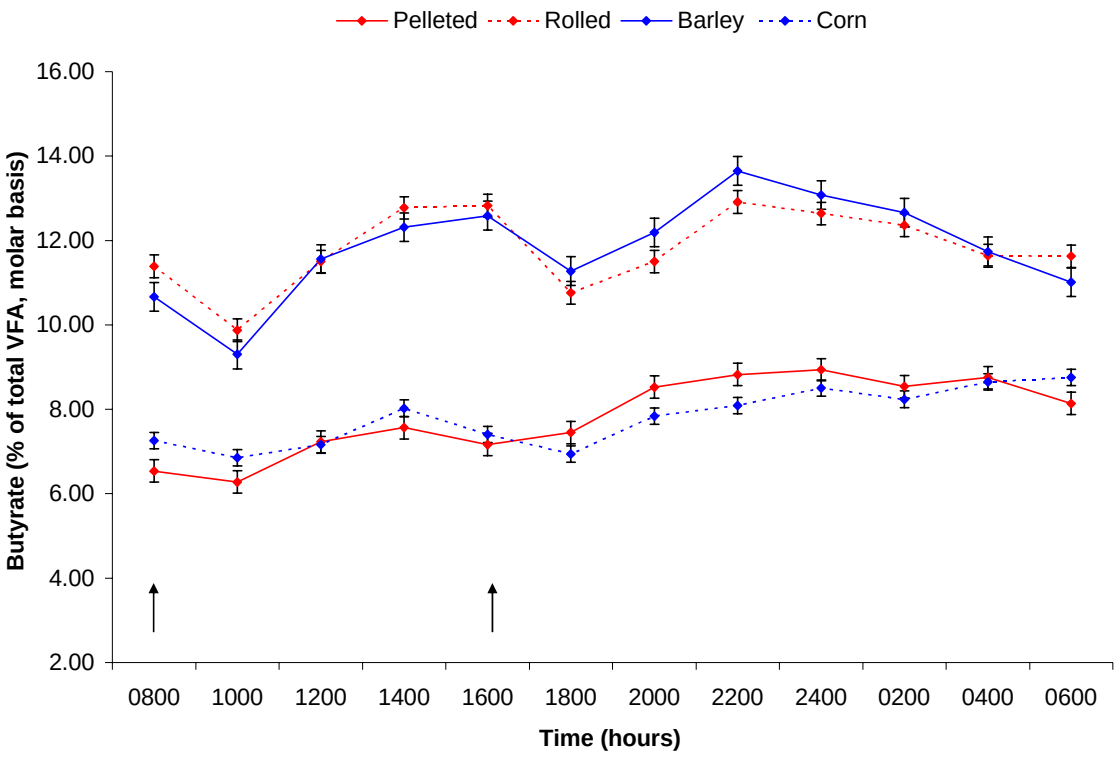

Figure 4. 3. Effects of processing (pelleted vs. rolled) and grain type (barley vs. corn) on ruminal molar proportion of butyrate. Arrows represent feeding times.

the opposite occurring as the proportion of propionate increases (Van Houtert 1993). A lower acetate:propionate ratio also means that more energy is being partitioned towards muscle accretion (Beauchemin et al. 2003a), something that is desirable in the feedlot setting. If more acetate is produced, increasing the acetate:propionate ratio, it is at the expense of the production of the other VFAs, especially propionate. If there is insufficient propionate to carry out the required gluconeogenesis, glucogenic amino acids will be used for this purpose, and are no longer available for protein synthesis (Van Soest 1994). Results from the current study support the results of Yang et al. (2000) and Čerešňáková et al. (2005) showing that increased processing of grain in high grain diets results in a decreased acetate:propionate ratio. In the current study ratios ranged from 1.1 to 2.4. These values are well within the range of values published, 1.0 to 2.5 (Ghorbani et al. 2000; Beauchemin et al. 2003a; Jaeger et al. 2006).

Rumen pH and rumen VFA concentration are related. As VFA build up in the rumen, rumen pH is depressed (Narayanan et al. 1997; Nocek 1997; Bach et al. 2005). However, rumen pH also impacts VFA concentration and profile. The pKa values of acetate, propionate, and butyrate are 4.75, 4.87, and 4.81, respectively (Rémond et al. 1996). Therefore at pH 6 to 7 most are in their dissociated form but at lower pH levels, such as would occur when high grain rations are fed, VFA are more likely to be in an undissocited state (Rémond et al. 1996) which increases their absorption rate (Dijkstra et al. 1993). However, when fed large amounts of readily fermentable carbohydrate, the rate of VFA production may be greater than absorption, and VFA accumulate, depressing pH further (Nocek 1996, Narayanan et al. 1997, Beauchemin et al. 2003a).

Rumen pH helps determine the proportion of NAD^+ present relative to NADH, and this impacts the VFA profile by favouring production of some VFA over others. Acetate production is favoured when the rumen has a high NAD^+:NADH ratio (Van Houtert 1993), whereas both propionate and butyrate-producing pathways require the donation of an electron from NADH so production of these VFA is favoured when the NAD^+:NADH ratio is low. When an animal is fed a high forage diet, rate of fermentation is low, resulting in a relatively high rumen pH (6.5 to 7), NAD^+:NADH ratio is high, and flow rate of carbohydrate to pyruvate is decreased (Van Houtert 1993). More acetate is produced and a low rate of carbon flow means a decrease in the flow of carbon through the pathways that produce propionate and butyrate (Van Houtert 1993). A high rumen pH favours acetate production over propionate production while a low rumen pH has the reverse effect. Since butyrate production also requires the donation of an electron, butyrate production is increased as well (Van Houtert 1993). A ruminant fed a rapidly fermentable feed such as a high-grain diet, therefore, will produce more propionate than acetate, and butyrate production will be increased, and a ruminant with a lower rumen pH will have lower levels of acetate than one with a neutral rumen pH. The same effect is often observed when a more highly-processed grain diet is fed (Yang et al. 2000, Čerešňáková et al. 2005, Beauchemin et al. 2001).

When rumen pH is relatively high, acetate production is favoured (Van Houtert 1993). Steers fed rolled grain had higher ($P < 0.05$) rumen pH measurements than steers fed pelleted grain, therefore it may be expected that in the current trial the steers fed rolled grain would have a higher percentage of acetate than the steers fed pelleted barley. This was not the case. Though rumen pH was higher for steers fed rolled grains, rumen

acetate levels did not differ ($P > 0.05$) between these groups. This could be because rumen pH measurements in both groups were relatively low. When rumen pH is 6.5 to 7, acetate production is favoured (Van Houtert 1993). Average rumen pH for the rolled grain-fed steers was 6.1, lower than 6.5. Therefore the depression in rumen pH in the pelleted steers could be the reason for the increased propionate production observed in steers fed pelleted grain. Steers fed pelleted grain had higher ($P < 0.05$) levels of propionate, results similar to that of Yang et al. (2000). This increase in propionate lead to a decreased ($P < 0.05$) acetate:propionate ratio in pelleted grain-fed steers compared to steers fed rolled grain. A decreased acetate:propionate ratio in animals fed highly processed diets was also observed by Yang et al. (2000) and Čerešňáková et al. (2005).

The lack of effect of grain type on molar proportion of acetate, propionate, and butyrate, or on acetate:propionate ratio is not surprising. Other researchers (Foley et al. 2006, Rotger et al. 2006) also observed no effect of grain type on rumen VFA profile or acetate:propionate ratio when comparing barley and corn-based diets.

4.3.2.3 Rumen Osmolality

In the present study, there was no effect ($P > 0.05$) of treatment or interaction on osmolality (Table 4.2). High ruminal osmolality is a concern as it can lead to a damaged rumen wall and liver abscesses (Owens et al. 1998). The lack of effect of grain processing on rumen osmolality may explain why in the feedlot study there were no treatment effects on the occurrence of liver abscesses. Rumen osmolality values measured in the current study ranged from 248.4 mOsm L^{-1} to 316.3 mOsm L^{-1}. These values fall within the range of normal rumen osmolality values (261 to 355 mOsm L^{-1})

(Owens et al. 1998; Brown et al. 2000; Bevans et al. 2005). However, under acidotic conditions osmolality has been reported to rise to as high as 515 mOsm L^{-1} (Owens et al. 1998). Marshall et al. (1992) and Campbell et al. (1992) compared osmolality measurements of steers fed ground or rolled grain diets and also found that rumen osmolality did not differ between the two groups. Chewing activity also did not differ between the two groups, and the authors assumed that saliva production was constant between the ground and rolled grain fed animals, explaining the lack of processing effect on osmolality. As shown in section 4.3.3 chewing activities were similar in the current study as well. As such, similar saliva production could be the reason for the lack of processing effect on rumen osmolality in the present study.

There was an effect ($P < 0.05$) of time on rumen osmolality. Rumen osmolality was lowest immediately before each feeding, rose to its highest level following feeding, then fell again until the next meal (Figure 4.4). This is similar to results reported by Bevans et al. (2005). This pattern is to be expected as fermentation results in the production of VFA, and as VFA concentration increases, so does osmolality.

4.3.2.4 Rumen Ammonia

There was no effect ($P > 0.05$) of grain type on rumen ammonia concentration, but steers fed pelleted grain tended ($P = 0.09$) to have higher overall rumen ammonia levels (Table 4.2). Failure to see an effect of grain type on rumen ammonia is somewhat surprising. A lower rumen ammonia concentration in barley- vs. corn-fed cattle has been observed by McCarthy et al. (1989) and Casper et al. (1999). This was attributed to a greater rate of degradability in barley, and also a high rate of microbial protein synthesis

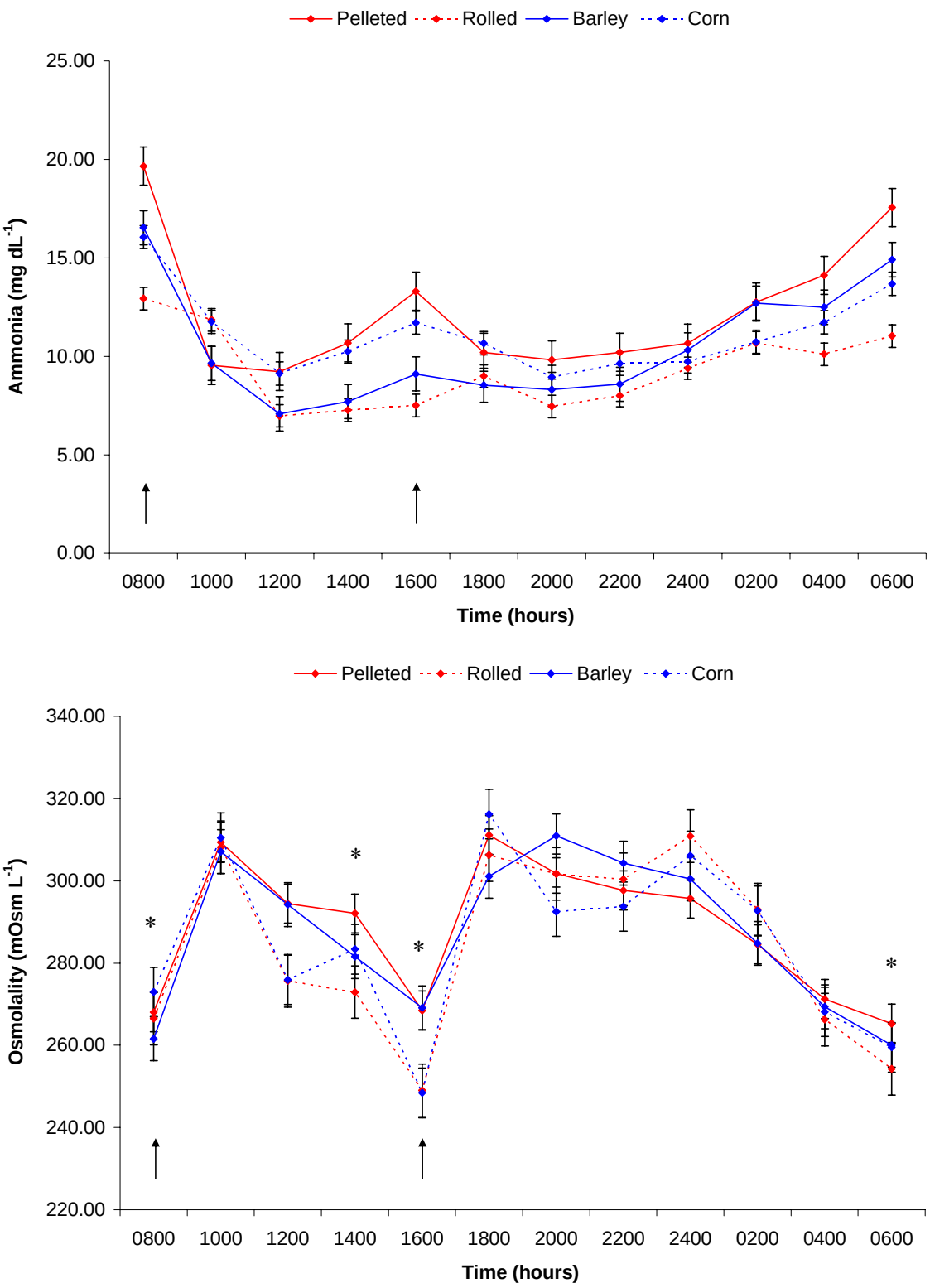

Figure 4. 4. Effects of processing (pelleted vs. rolled) and grain type (barley vs. corn) on rumen ammonia concentration and osmolality. *Processing means (±SEM) are different ($P < 0.05$). Arrows represent feeding times.

(Casper et al. 1999). With beef cattle fed higher levels of grain, rumen ammonia concentration has been observed to be higher with barley vs. corn-based diets (Surber and Bowman 1998; Rotger et al. 2006). Similar to the current study, Khorasani et al. (2001) observed no effect of barley vs. corn on rumen ammonia concentration.

The effects of processing grain on rumen ammonia concentration have also been variable. Yang et al. (2000) found that feeding highly processed grain resulted in higher rumen ammonia concentrations. Koenig et al. (2003) found that greater processing tended to increase rumen ammonia levels while Beauchemin et al. (2001) and Bengochea et al. (2005) found little influence of processing on rumen ammonia concentration. Some differences exist between the current study and the published research. Beauchemin et al. (2001) observed no effect of processing on rumen pH. Since rumen pH can affect rumen ammonia concentration, a lack of effect of processing on pH could also result in a lack of effect of processing on rumen ammonia concentration. Bengochea et al. (2005) used medium-concentrate growing diets as opposed to high-concentrate finishing diets as in the current study. The trend towards steers fed pelleted grains in the current study having increased rumen ammonia levels could be due to the decreased pH observed in the pelleted grain treatment group.

In the present study, there was a time by processing interaction ($P < 0.05$). The nature of this interaction is such that the rumen ammonia concentration of steers fed pelleted grain fell after feeding, then rose again until the next feeding (Figure 4.4). The rumen ammonia concentration of steers fed rolled grain followed a less predictable pattern than steers fed pelleted grain, particularly at the times when rumen ammonia concentration differed ($P < 0.05$) between the treatment groups. However, the overall

pattern of the concentration falling after feeding and rising before the next feeding is still apparent. This is similar to diurnal patterns for rumen ammonia observed by other workers feeding high grain rations to feedlot cattle (Pylot et al. 2000; Beauchemin et al. 2003a).

4.3.3 Feeding Behaviour

There was no effect ($P > 0.05$) of processing or grain type on minutes spent chewing (Figure 4.5). Time spent chewing was the sum of minutes spent eating and minutes spent ruminating in 24 h, neither of which were influenced ($P > 0.05$) by treatment. Time spent chewing in a 24 h period ranged from 249 to 344 min, time spent eating ranged from 80 to 99 min, and time spent ruminating was 160 to 246 min. These results are comparable to those of Beauchemin et al. (2001) who also observed feedlot steers fed high concentrate diets.

Much research has gone into time spent chewing by cattle fed different diets (Beauchemin et al. 2001; Maekawa et al. 2002a; Maekawa et al. 2002b), and published results range from 720 to 848 min day^{-1} (Maekewa et al. 2002a; Maekawa et al. 2002b) in dairy cattle to 318 to 388 min day^{-1} in beef cattle (Beauchemin et al. 2001).

Time spent chewing is important as chewing helps influence rumen passage rate and increases saliva flow (Ørskov 1986; Mathison 1996; Allen 1997; Maekawa et al. 2002a). Saliva flow is important because of its buffering properties (Ørskov 1986; Allen1997; Galyean and Rivera 2003; Yang and Beauchemin 2006a). In fact, nearly half of the buffering of acids of rumen fermentation are provided by saliva (Allen 1997; Owens et al. 1998).

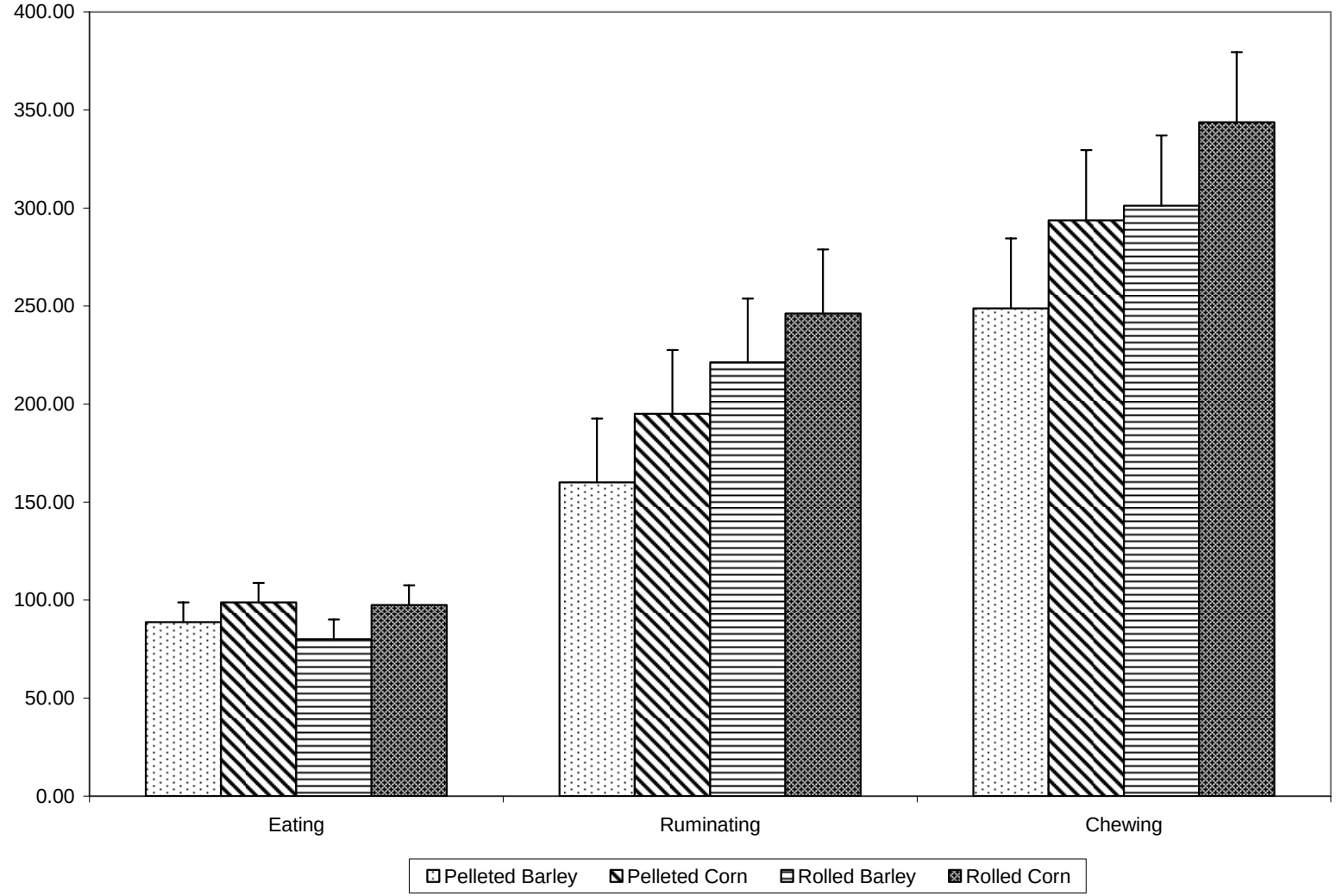

Figure 4. 5. Minutes spent eating, ruminating, and chewing in 24 h.

Research by Beauchemin et al. (2001) found that while increased processing of barley did not affect time spent eating, it did reduce ruminating time and had a tendency to reduce total chewing time. These results contrast with the results from the current trial, where there was no effect ($P > 0.05$) of processing on time spent chewing, ruminating, or eating. Since there was no difference in total time spent chewing, it can be assumed that there was no difference in saliva secretion and buffering that can be attributed to processing or grain type.

Recently it has been found that saliva production may not always be sufficient to neutralize the rumen after a highly fermentable meal (Yang and Beauchemin 2006a). In research by Campbell et al. (1992) and Marshall et al. (1992), when steers were fed high concentrate diets with hay as a forage, animals fed ground or rolled concentrate spent similar amounts of time eating and ruminating, but the rumen pH of the ground grain fed steers decreased at a faster rate than that of steers fed rolled grains. The results of the current study are similar in that pelleted grain-fed steers exhibited more acidic conditions in the rumen, however time spent eating or ruminating did not differ.

4.4 Implications and Conclusions

Processing grain by grinding and then pelleting influences rumen fermentation. Steers fed pelleted grain had lower ruminal pH, a greater proportion of propionate, a decreased acetate:propionate ratio and higher rumen ammonia levels at certain points during the day. When corn was removed from the model and only barley was analyzed, steers fed the pelleted barley diets showed lower ruminal pH, and higher total VFA concentration and propionate levels. Eating behaviour was not affected by grain processing. Steers spent the same amount of time eating, ruminating, and chewing

regardless of whether the concentrate was rolled or ground and pelleted. As such it can be inferred that processing the grain did not negatively impact buffering from saliva.

Differences in rumen fermentation parameters may explain the differences in performance between steers fed pelleted barley and those fed rolled barley in the feedlot trial. Decreased rumen pH and increased concentration of VFA can signal SARA. If steers in the feedlot trial fed pelleted barley were suffering from SARA, it may explain the reduced DMI that resulted in decreased ADG and increased days on feed. Pelleted barley-fed steers had higher molar proportions of propionate. Propionate is known to by hypophagic (Allen 2000; Oba and Allen 2003), and therefore this increase in ruminal propionate could also contribute to the depression in DMI observed in steers fed pelleted barley in the feedlot trial. The decreased acetate:propionate ratio may be why steers fed pelleted barley had improved feed efficiency.

Results from this study show that processing grain can have an impact on rumen fermentation parameters, and these changes may indicate SARA. However, some of the changes, such as a decreased acetate:propionate ratio are beneficial in the feedlot setting, as they lead to higher feed efficiency.

5.0 GENERAL DISCUSSION AND CONCLUSIONS

Foreign markets are interested in importing feed barley from Canada because of the efficient gains and desirable carcasses produced by barley fed cattle. In particular, these countries are interested in the bright white carcass fat that results from feeding barley. Unfortunately, due to tariffs and transportation costs it is not economically feasible to export whole barley to these countries. One solution proposed was to develop a highly processed barley product, and include in this product a western Canadian-grown protein source. Processing the barley by grinding then pelleting it with canola meal will not only decrease transportation costs, but will also increase the digestibility of the grain (Mathison 1996). Processing grain also leads to increased ADG and improved feed efficiency (Mathison 1996; Nocek 1997; Koenig et al. 2003). Due to physical differences between barley and corn, barley is much more rapidly fermented in the rumen (Yang et al. 2000; Foley et al. 2006; Rotger et al. 2006). While feeding processed barley has benefits, feeding very highly barley which has been highly processed, such as grinding, can carry risks. Grinding barley can lead to increased fines and dustiness which have been shown to decrease DMI (Mathison 1996; Beauchemin et al. 2001). Ground grain may also decrease time spent chewing which can decrease saliva flow and therefore rumen buffering via saliva (Ørskov 1986). Extensively processed grain can result in very rapid and complete digestion resulting in accumulation of VFA in the rumen and decreased rumen pH which can decrease microbial protein synthesis and fibre digestion (Ørskov 1986; Nocek 1997; Koenig et al. 2003). The increased rate of fermentation can put cattle at increased risk of developing SARA, a metabolic disease characterized by decreased rumen pH, impaired microbial function, and changes in rumen fermentation

patterns, such as increased levels of rumen VFA (Nocek 1997; Owens et al. 1998; Krajcarski-Hunt et al. 2002). Performance is negatively impacted by SARA as it can increase variation in DMI, and DMI and ADG can be reduced (Nocek 1997; Krajcarski-Hunt et al. 2002; Galyean and Rivera 2003).

If this pelleted barley product is to be exported it must be demonstrated that cattle not only perform as well as cattle fed rolled barley (the traditional method of processing barley in the feedlot), but also produce a similar carcass. This is particularly important with fat colour, which can be altered by diet (Yang et al. 2002; Boles et al. 2004). Diet has also been shown to alter the fatty acid profile of carcass fat (Demeyer and Doreau 1999; Griswold et al. 2003; Mir et al. 2003a). The objective of this research was to determine the effects of feeding a highly processed grain product to feedlot cattle during the backgrounding and finishing phases, with particular emphasis on feedlot performance, carcass quality, rumen pH and other fermentation variables impacted by SARA, and feeding behaviour.

This study consisted of two trials. First a feedlot trial comprised of 350 crossbred steers fed one of two dietary treatments using ground barley/canola meal pellets (PB) or rolled barley (RB) as the concentrate. This trial looked at the effect of feeding ground barley/canola meal pellets on performance parameters such as DMI, ADG, feed efficiency, and backfat and *l. dorsi* gain throughout the backgrounding and finishing phases. At slaughter, carcass data was collected so carcass quality and composition could be compared. Livers were scored for presence and severity of abscesses. Subcutaneous fat samples were collected for colour analysis, and the fatty acid profile of intramuscular fat was analyzed. As increased processing has been shown to decrease DMI due to

increased incidence of fines, orts were collected from each bunk every 2 weeks during finishing and analyzed for particle size.

During backgrounding, steers fed PB performed better than steers fed RB as they gained the same amount of weight using less feed. During finishing, when proportion of concentrate in the diet was higher, DMI was depressed to the point that ADG was also depressed. This leads to the conclusion that the highly processed nature of the grain does not lead to the negative effects often observed when feeding rapidly fermentable feed to cattle (Ørskov 1986; Owens et al. 1998; Galyean and Rivera 2003) until the PB makes up a large proportion (>80%, DM basis) of the diet. Though there were some differences in the carcasses of steers fed PB vs. RB they were relatively minor differences proving that PB can be fed to cattle to produce a carcass similar to that of cattle fed RB. Steers fed PB showed increased variation in DMI over a greater number of days than steers fed RB. Since steers were handled in an identical manner, and degree of barley processing was the only factor that differed, it can be assumed that the increased variation in DMI is due to differences in feed. The reduced performance during finishing and over the entire trial, taken together with the increased variation in DMI indicates that these steers were suffering from SARA. One promising aspect of PB is that while it decreased DMI and ADG during finishing and throughout the entire trial, feed efficiency was improved. If the reason behind the reduction in DMI can be discovered and corrected, overall feedlot performance should improve to a level comparable to or greater than that observed in steers finished on RB.

The poor performance and increased variation in DMI in steers fed PB in the feedlot trial indicated SARA. To determine if the steers were in fact suffering from this

disorder, a metabolism trial was conducted. This trial was a 4x4 latin square utilizing 4 ruminally cannulated crossbred steers. Dietary treatments were 2x2 factorial, with degree of processing (pelleted vs. rolled) and grain type (barley vs. corn) as the factors. After steers were adapted to the diets, rumen contents were sampled every 2 h for 24 h, and analyzed for pH, VFA concentration and profile, ammonia concentration, and osmolality. Chewing behaviour was then observed every 5 min for 24 h and time spent eating, ruminating, and chewing calculated.

These results show that grinding then pelleting grain does affect rumen fermentation. The reduced pH observed in steers fed pelleted grain diets is indicative of SARA. When corn was removed from the statistical model, rumen pH was reduced and rumen VFA concentration was increased, another sign steers fed PB were suffering from SARA. Feeding pelleted grain decreased the acetate:propionate ratio which is beneficial in the feedlot, but it also increased the level of propionate which has been shown to suppress appetite. Chewing behaviour was not incluenced by treatment which means processing did not negatively affect rumen buffering via saliva flow. Results from the metabolism trial indicate steers in the feedlot trial were suffering from SARA. The poor performance exhibited by steers fed PB in the feedlot trial is most likely due to SARA, though depression in DMI caused by increased incidence of fines and increased levels of propionate may have also contributed.

The hypothesis of this study was that barley which has been ground and put in a pellet along with canola meal can be used effectively for backgrounding and finishing cattle. These results show this hypothesis to be true during backgrounding. However, during finishing when the PB product was included in the diet at very high levels the

DMI was depressed enough that overall performance was negatively impacted. There were some promising aspects of this feed. Carcasses from cattle fed PB were similar to those of cattle fed RB. In particular, grinding and then pelleting barley did not change the colour of the fat, a very important aspect if the feed is to be exported to countries desiring a bright, white fat. Probably the most important observation from this study, however, was that though DMI was reduced, feed efficiency was improved for steers fed PB. This makes it very important to find the reason behind the reduced DMI for further development of this product. Further research could include using a protein source in the pellet that is also high in fibre, including buffers in the diet to reduce the risk of SARA, improving pellet quality to reduce the incidence of fines, or utilizing other bunk management practices aimed at reducing SARA.

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Appendix A. Fat Extraction

Fat was extracted from the ground meat samples using a procedure based on that of Bligh and Dyer (1959). Approximately 15 g of the ground tissue was weighed into an Erlenmeyer flask and the weight recorded. The 15 g was comprised of sub-samples from several different areas of the ground sample. In the fumehood, 25 mL of chloroform and 50 mL of methanol were added to the flask and this mixture was homogenized for 2 min. Next 25 mL of chloroform was added and the sample was homogenized for 30 sec, followed by the addition of 25 mL of double-distilled water and another 30 sec of homogenizing. Finally, another 25.5 mL of chloroform was added to the mixture and homogenized for 1 min. Between the addition of each solvent, the blade of the homogenizer was cleaned using tweezers. The homogenate was then filtered through Whatman #1 filter paper in a 250 mL Buchner funnel into a 250 mL sidearm flask. The Erlenmeyer flask was rinsed twice with 5 mL of chloroform which was then poured over the homogenate and filtered. The filtrate was transferred into 250 mL separatory funnels, and a few crystals of an antioxidant (*tert*-butylhydroquinone; Sigma-Aldrich, Inc.) was added before placing a stopper in the top of the funnel and allowing the filtrate to sit overnight. A biphasic solution resulted, with the bottom layer containing the chloroform and non-polar lipids. This layer was removed from the separatory funnel into a 100mL graduated cylinder fitted with a glass funnel and Whatman #1 filter paper. A small amount (approximately 1 g) of anhydrous sodium sulfate was first placed in the filter paper to remove any water that may have gotten transferred with the chloroform layer. The exact volume of the chloroform layer was recorded, and then the solution was transferred to a 250 mL round-bottomed flask. Two aluminum weighboats were dried

overnight in a 100ºC oven, labeled according to sample, and weighed. The weight was recorded. One 5 mL aliquot of the cholorform layer was added to each weighboat, and these weighboats were set aside to dry in the fumehood. These were used to determine amount of fat extracted. The sample remaining in the round-bottomed flask was then evaporated using a rotary evaporator set to 50ºC. The fat was transferred to a 10mL screw-top test tube and any remaining chloroform was evaporated under a stream of nitrogen gas. Before sealing vials with the screw-tops, test tubes were flushed with nitrogen. Tubes were then stored at -20ºC until methylation.

Appendix B. Fatty Acid Methylation

Fatty acids were methylated for analysis via gas chromatography (GC). The procedure used was based on the procedure of Keough and Kariel (1987). Approximately 10 mg of extracted fat was weighed into a clean, dry 5 mL reaction vial (Reacti-Vial™; Peirce Products, Inc.) and the weight was recorded. The internal standard used was methylated C19:0 in chloroform at a concentration of 2.5 mg mL^{-1} and 100 μL of this was added to the 10 mg of fat. A methylation mixture was made by weighing approximately 7 mg of *tert*-butylhydroquinone into a 50 mL volumetric flask. Approximately 25 mL of methanol was added to the flask, followed by 3 mL of sulfuric acid. The solution was brought up to a volume of 50 mL by adding more methanol. After transferring the methylation mixture to a beaker, 2 mL of it was added to the Reacti-Vial™. The methylation mixture was made fresh for each batch of methylations as it does not keep. The vial was then vortexed and placed in 60ºC heat overnight. The vial was cooled to room temperature and 1mL of double-distilled water was added before vortexing for 30 sec. Next 1.5 mL of hexane was added, the sample was vortexed and the top layer, the hexane layer, was transferred to a labeled 16x100 mm test tube. This process of adding the hexane, vortexing, and removing the hexane layer, was repeated 2 more times. The sample was then rinsed by adding 1.5 mL of double-distilled water, mixing gently using a Pasteur pipette, then removing the water layer. Another 1.5 mL aliquot of double-distilled water was added, followed by gentle mixing except this time the bottom hexane layer was removed using a fresh Pasteur pipette and transferred to a 10 mL screw-top test tube. A few crystals of *tert*-butylhydroquinone were added to each test tube before the sample was added. Hexane was evaporated off under a stream of nitrogen

and fatty acid methyl esters were re-suspended in 1 mL of GC-grade hexane. Samples were filtered through a glass filter syringe into GC vials. The GC vials were flushed with nitrogen before being capped and wrapped in parafilm. Samples were stored at -20ºC until analysis on the GC.

Appendix C. Cattle Slaughter Criteria

Table C.1. Number of cattle from each treatment group slaughtered at backfat thickness and number slaughtered at bodyweight.

	Basis	
Treatment	12 mm backfat	680 kg bodyweight
Pelleted	107	69
Rolled	125	47
Total	232	116